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THE MERCURY-VAPOR QUARTZ LAMP.*

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Synopsis: In the following paper the author explains the difference between the standard mercury-vapor tube lamps and the quartz mercury-vapor lamps. He gives some interesting figures and facts on the characteristics of quartz, and information as to the construction of the burners. A description is given of the various types of lamps manufactured and a number of curves and drawings illustrate the principal electric and photometric characteristics. The color of the light from the quartz lamp is similar to that from the standard tube lamp with a certain amount of red added, thus giving a closer approximation to daylight. The wide application of the lamp in the industrial field is shown by figures from a few installations. The high efficiency of the quartz lamp is shown by a given comparison with several types of arc lamps. A few unique installations are described explaining the advantages of the light. Figures are also given to show the maintenance cost of the lamp. While it has been developed as an illuminant, the lamp plays an important part in the chemical and physiological world due to its ultra-violet radiation. Experiments have been made showing its effectiveness for the sterilization of milk and water. Considerable experimenting is being done at the present time to determine its availability in processes where sunlight is a factor and new methods have been worked out and new fields opened up for the bleaching of cotton and vegetable fabrics, testing the permanency of colors, deblooming of oil, and in physiological and photographic work.

INTRODUCTION.

The mercury-vapor quartz lamp, while based on the same fundamental principles as the ordinary glass tube mercury-vapor lamp, differs from the latter in its general characteristics to a

* A paper read at the seventh annual convention of the Illuminating Engineering Society, Pittsburgh, Pa., September 22-26, 1913.

great extent both electrically and mechanically. The main similarity between the two lamps is in the application of the principle of the passage of an electric current through mercury vapor to produce light. However, the lamps differ in regard to the character of the container, the pressure of the vapor, the temperature of the arc, the efficiency, the color and in other minor respects.

The tube lamp can be made in almost any feasible size, depending upon the impressed electromotive force, or the ability of the seals to carry the current, and the proper proportioning of the cooling surface or the "condensing chamber."

The standard glass tube lamps are 1 in. (2.54 cm.) in diameter and the voltage drop of the vapor column when operated at 3.5 amperes is approximately 1.25 volts. The volt-ampere char-

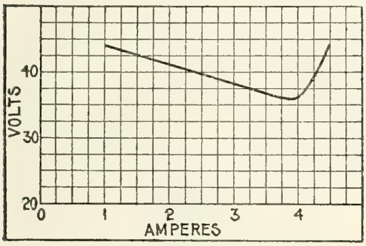

Fig. 1.—Volt ampere characteristic of 20-inch mercury-vapor tube.

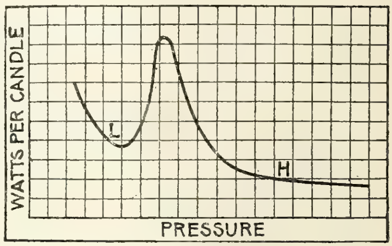

Fig. 2.—Variation of efficiency of mercury-vapor lamp with respect to pressure of vapor.

acteristic of a 21 in. (53.34 cm.) tube is shown in Fig. 1. This curve shows the entire voltage drop across the tube which includes the drop in the electrodes as well as in the vapor column. At 3.5 amperes, the normal operating current, the pressure of the vapor corresponds to about 1 mm. of mercury. This pressure depends upon the temperature of the electrodes. As this temperature is increased, the pressure rises and forces the tube voltage up to a point where the proportion of the tube voltage to the line voltage is so great that the arc becomes unstable and the lamp drops out.

However, by the use of a short container with a light giving column of approximately 4⅛ in. (10.5 cm.) and with a drop along the vapor column of 40 volts per inch (2:54 cm.) at 3.3 to 3.5 amperes, the temperature of the arc is materially raised and consequently the pressure is increased enormously and a lamp is obtained which is much more efficient than the low pressure lamp.

Fig. 2 shows this variation of efficiency of mercury-vapor lamps by increasing the pressure. The point marked "L" represents the most efficient point of the standard tube lamp at a point corresponding to a pressure of approximately 1 mm. of mercury, point H representing that of a high pressure lamp at a pressure of approximately one atmosphere. By increasing the pressure in this respect, the efficiency is practically doubled.

THE QUARTZ BURNER.

With a mercury-vapor lamp running at a pressure of one atmosphere, the temperature in the center of the arc has been calculated by Kuch to be between 4,000° and 6,000° C. As ordinary lead glass will soften at about 300° C. it is not desirable to use it as a container for the high pressure lamps, and therefore, quartz glass, which has an extremely high melting point, has been substituted.

Quartz for vessels and tubes for laboratory work has been used for a number of years, but it is only with the advent of the high pressure mercury-vapor lamp that it has been brought into use on a large scale. The quartz as used in these commercial lamps is at present all made abroad by fusing the tubes from rock crystal. Quartz, as is well known, is one of the constituents of glass being known as silicon dioxid, SiO_2, and as the percentage of quartz is increased, the heat resistance of the glass is correspondingly increased until with the use of pure silicon dioxid fused quartz is obtained. This fused quartz is extremely hard. It will scratch glass very readily, its degree of hardness being known as No. 7 on Moh's scale where the diamond ranks as No. 10. It is transparent and practically colorless though at times it has slight streaks through the tubes. The tubing is made up in the form of lamps or burners as in Figs. 3 and 4. The working of this quartz into the form of a lamp entails not a little labor and is an extremely difficult operation. As the temperature of the ordinary Bunsen flame is only 1,200° C. and it requires a heat of 1,500° C. to soften the quartz, a flame is used with a temperature of 2,200° C. to properly work it. This flame is composed of oxygen and a special gas extremely rich in carbon. The quartz evaporates very quickly at a slightly higher temperature and it has not been found feasible to use the oxyacetylene flame of about 2,400°. The coefficient of expansion of quartz is prac-

tically nil and a mass of hot quartz can be plunged into water without cracking. In working it in the flame, it does not like glass readily run or flow into the desired shape, but must be pushed into place. This often requires considerable force. The quartz tubing before being worked into a burner is fairly tough and will withstand a blow which would readily shatter glass. After working it, however, it becomes more brittle. In the ordinary state it can readily be drawn out into a long thin thread, which when cold becomes somewhat elastic, while glass in this state is extremely brittle.

The burners, as shown in Figs. 3 and 4, differ essentially in the construction of the seals. They both contain the luminous tube which varies in size depending upon the applied voltage and current. The condensing chamber of the quartz burner is placed

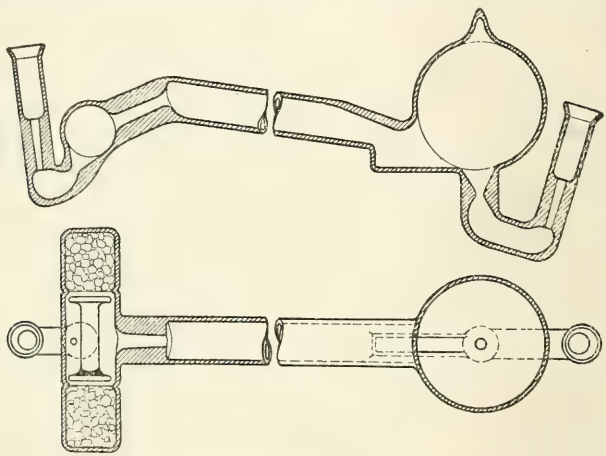

Fig. 3.—Quartz burner with invar seal.

on the positive end in contra-distinction to the low pressure lamp, where it always is at the negative end. In some cases radiation is provided for the burners by attaching metal vanes or radiators to the lateral tubes. This, however, does not give as good an effect as the condensing chamber. If provision is not made for proper cooling by the use of some such method, the temperature of the arc increases with consequent increase of vapor pressure which may finally become so high as to cause a blow-out in any weak part of the quartz.

One of the greatest difficulties in the manufacture of quartz burners for commercial purposes is that of providing a proper means of introducing current to the electrodes. The coefficient of expansion of fused quartz is extremely small, approximately 0.5×10^{-6}, which is about one-twentieth that of platinum. It is thus seen that the use of platinum wire for leading in the current is not feasible.

The first burners put on the market were equipped with what is known as the invar seal, Fig. 5. Invar steel or nickel steel has a coefficient about twice that of fused quartz, but as it is a forged metal and loses this property when heated to a red heat, it is not possible to fuse it directly to the quartz, and a stopper seal was

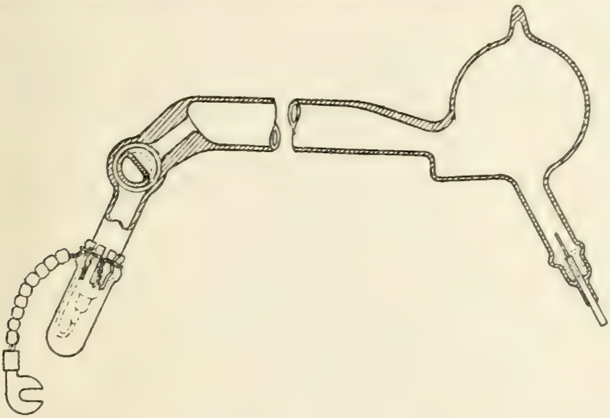

Fig. 4.—Quartz burner with new type seal.

evolved. This consists of a cone shaped piece of metal which is inserted in a quartz tube drilled and ground to the proper size. As a seal of this type cannot be made air tight, it is covered with mercury to insure a hermetically sealed joint and the mercury is kept in place by being covered with a cement compound, which prevents spilling, a copper lead being soldered to the invar to lead in the current. While this seal has proved satisfactory in providing an air tight joint, it has proved extremely expensive to manufacture, due to the labor involved in grinding the quartz. On this account a simpler type of seal has been evolved which is now being used on all burners.

For reasons connected with the patent situation respecting this seal, it is thought best to withhold full description thereof until

a future date. A general view of the lamp with the new type of seal is shown in Fig. 4 and it will be seen that it differs from the invar lamp solely, or chiefly, in regard to the seals. The lateral chamber at the negative end of the lamp is partly filled with broken quartz, which eliminates the necessity of completely filling the chamber with mercury.

A small cone-shaped passage is provided from the negative electrode to the luminous tube. The commonly accepted theory of the action of the conical passage is open to question, but it may be restated here for what it is worth. The theory is that, as the anode is hotter than the cathode under ordinary conditions, all the mercury would condense at the negative end of the tube, and eventually the arc would run on the seal. To keep the mercury at approximately the same level at the two electrodes, irrespective of temperature, the conical passage is provided, and as the mercury gradually fills up the negative end, the surface exposed

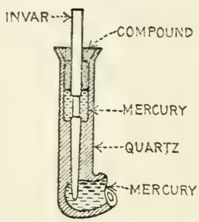

Fig. 5.—Detail of invar seal.

becomes smaller and smaller and the temperature of the mercury increases, causing more rapid evaporation, which tends to keep the level down to the proper point. If the mercury falls too rapidly, the action is reversed and condensation will occur until the proper point is reached. The narrowing of the mercury surface at this point also prevents flickering of the arcs, due to the small surface presented for wandering.

OPERATION OF THE QUARTZ LAMP.

The operation of the quartz lamp on commercial line circuits of direct current presents no marked difficulties if the lamps are properly adjusted at the start. At the present time lamps are manufactured for 110, 220 or 550-volt direct current circuits. As the 220-volt lamp is more generally used than the other two, the general characteristics of that lamp will be considered. It

should be borne in mind, however, that the figures, etc., given for the 220-volt lamp are proportionately the same as for the 110 and 550-volt lamps.

When a cold quartz lamp is first started, the vapor pressure is low and consequently there is a sudden inrush of current. The density of the vapor rapidly increases and the current falls very quickly, while the burner voltage increases in proportion. In about three minutes time a point almost normal has been reached and at the end of five minutes the current and voltage lines start to straighten out, that is to say, the current and voltage conditions tend to become constant. Figs. 6 and 7 show starting up

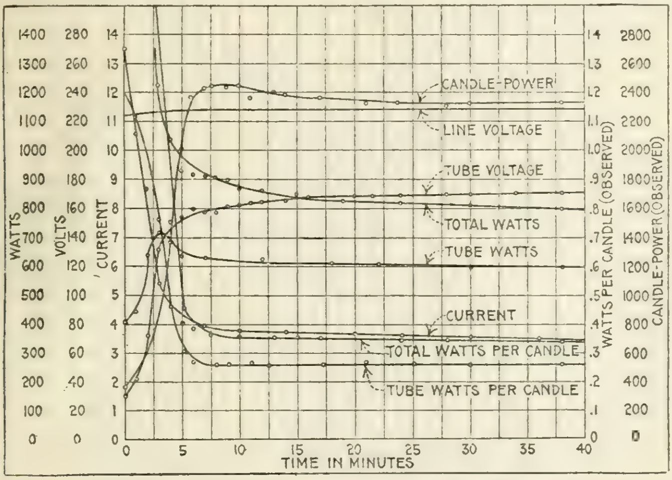

Fig. 6.—Time curve of 220-volt quartz lamp with globe on.

curves on the 220-volt burners. The one in Fig. 6 is equipped with a glass globe, while Fig. 7 shows curves on a burner running in open air.

It will be noted in Fig. 6 that at the end of 35 minutes the burner voltage is 168 with a current of 3.5 amperes, whereas for the same time in Fig. 7, the burner voltage is 150 at a current of 4.5 amperes. This illustrates one of the principal functions of the globe, by the use of which the heat radiated from the lamp is confined to the immediate vicinity of the burner preventing dissipation, which maintains the proper vapor pressure with consequent lowering of current.

The candle-power given on the curves is candle-power observed

at one angle and is given only as a means of comparison, as it does not represent the total candle-power of the lamp.

It will be noted that this candle-power takes a sudden rise and then gradually settles down, showing a better efficiency at a slightly lower vapor pressure.

Fig. 8 shows a time curve on a lamp set for 140-volt maximum burner voltage, in which it will be noted that the candle-power rise is more gradual.

As the burner starts up the light fills the entire space between the electrodes, but as the vapor pressure rises and the current settles down, the arc is drawn out in a thin stream and does not strike the walls of the burner.

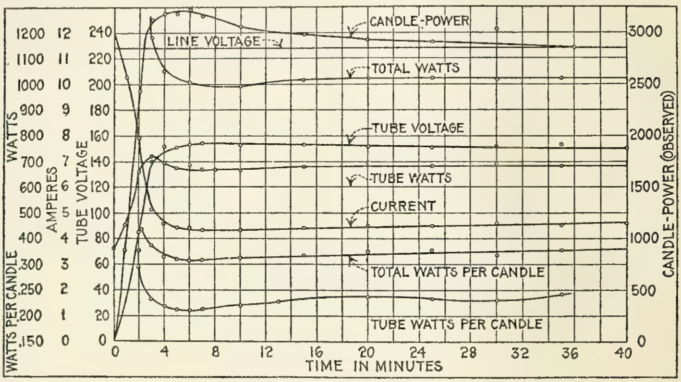

Fig. 7.—Time curve of 220-volt quartz lamp with globe removed.

Fig. 9 shows the stationary characteristic of the burner, that is, the volt-ampere characteristic, taken after the values have reached a normal running condition. The curve starts low with a gradual rise unitl it reaches a point a little beyond three amperes, where it begins to shoot up very rapidly and becomes practically a vertical line.

A change in the burner voltage of from 10 to 15 per cent. at the normal point of running will have practically no effect on the current, which remains fairly constant. If sudden rise in line voltage occurs, the burner voltage does not immediately change as the vapor pressure is not affected at that instant. All the excess voltage is taken up by the series resistance coil which causes increased current, and the burner then begins to get hotter

with consequent increase of burner voltage and the current falls back to practically its previous value.

An increase in line voltage thus simply tends to increase the burner voltage without any appreciable change in current. A

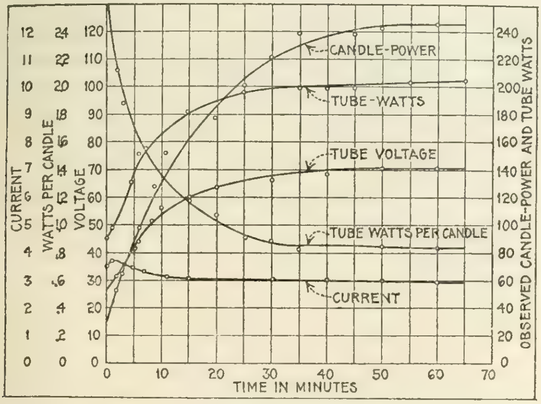

Fig. 8.—Time curve of 220-volt quartz lamp with globe on set for a maximum burner voltage of 140 volts.

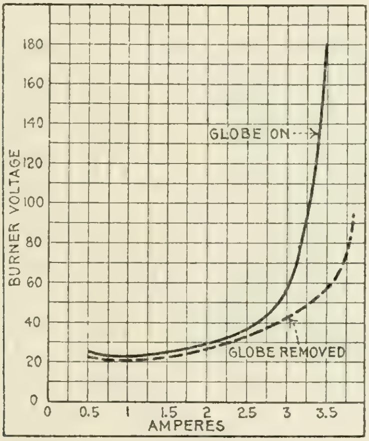

Fig. 9.—Starting characteristicts of 220-volt burners with and without globe.

decrease in line voltage would consequently mean a decrease in burner voltage.

While the operating voltage has been chosen at 165 volts, it will be seen from the curve of Fig. 11 that it would be more

economical to operate at even a slightly higher burner voltage, but due to the fact that if for any reason the lamp drops out and is then automatically relighted, under certain conditions the arc cannot be maintained and the lamp will pump, that is, will keep on tilting. The reason for this is that as the mercury runs down into the hot tube, during the short circuiting, an extremely intense vaporization is produced, raising the pressure to a point such that a higher line voltage than that provided is necessary to establish the arc. The point at which a burner cannot be relighted without cooling down the luminous tube is known as the "critical point" and for 220-volt burners is about 190 volts, while that of the 110-volt lamp is about 95 volts on a 110-volt line, but is raised to 120 volts on a 220-volt line, due to the increased backing provided.

COLOR.

In the low pressure lamp the light is produced by the luminescence of the mercury vapor and is strictly a line spectrum, while in the quartz burner operated at a higher temperature the vapor becomes heated to incandescence and a band spectrum is obtained which introduces a certain amount of red into the lamp but not enough to correct entirely the characteristic green color of the mercury-vapor lamp. The color of the quartz lamp, according to measurement by Dr. Ives with the Ives colorimeter, is exceedingly close in integral color to average daylight.

Fig. 10 shows relatively the spectrum of the low pressure lamp in a glass tube, the high pressure quartz burner with a glass globe and without a globe, and also a spectrum of sunlight. By comparing the sunlight spectrum with that of the glass tube lamp and the quartz lamp in a glass globe, it is apparent that all the ultra-violet radiation that is not present in sunlight is absorbed by the glass. The ultra-violet radiation without a globe, however, is extremely large. The wave-lengths extend down to somewhere near 200. These ultra-violet rays are chemically very active and open up an extremely wide field for the use of the quartz lamp in a great many physiological and chemical applications, which will be treated later.

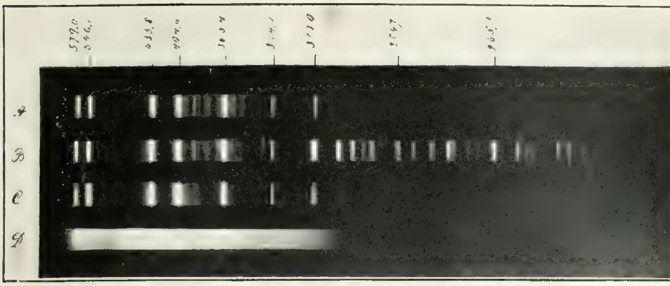

Fig. 10.—(A) Spectogram of standard glass tube lamp. (B) Spectogram of quartz burner without globe. (C) Spectogram of quartz burner with clear globe. (D) Spectogram of sunlight.

Fig. 10a.—Foundry illuminated by quartz mercury-vapor lamps.

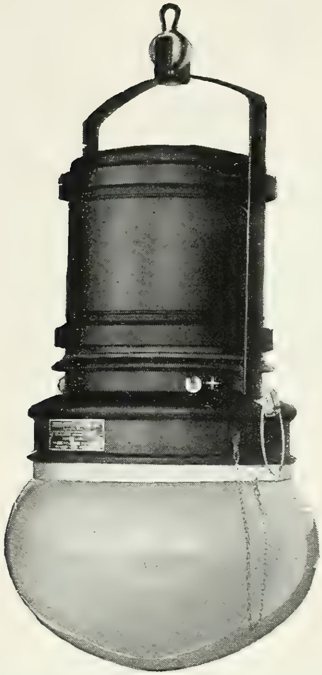

Fig. 16.—Exterior view of 220-volt quartz lamp.

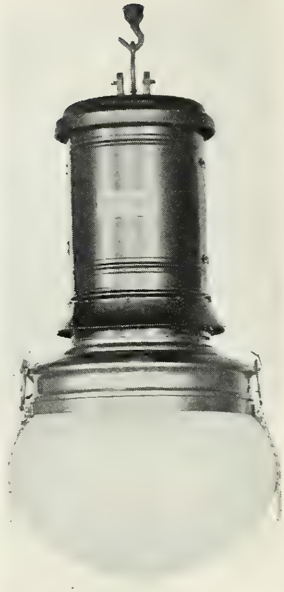

Fig. 17.—Exterior view of 550-volt quartz lamp.

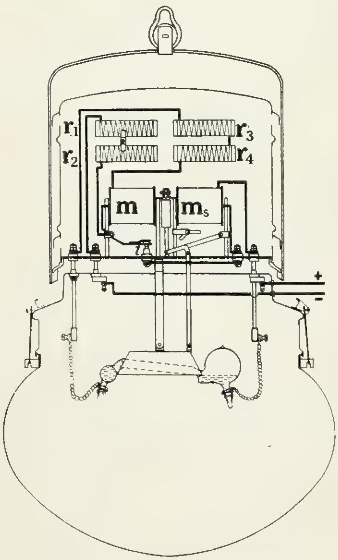

Fig. 18 —Diagram of wiring of 220-volt quartz lamp.

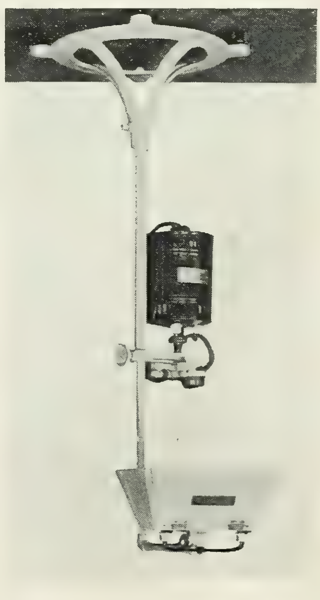

Fig. 19.—Quartz lamp laboratory outfit.

LIGHT CHARACTERISTICS.

Fig. 11 shows the difference in variation in candle-power of a burner due to current running in the open air and enclosed in a globe. For the same energy consumption at the normal operating point, there is about three times the light, due to the confining of the heat and the consequent increase of vapor pressure. The

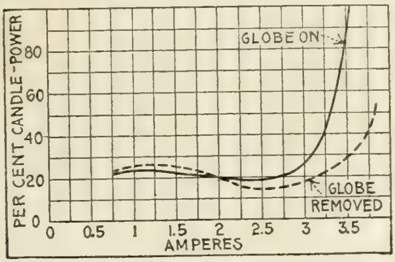

Fig. 11.—Variation of candle-power on quartz burner with respect to current.

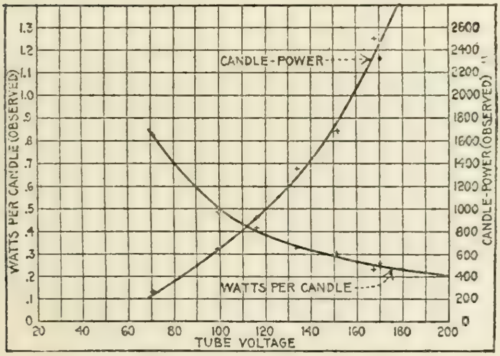

Fig. 12.—Variation of candle-power on quartz lamp with respect to burner voltage.

variation of candle-power with respect to the burner voltage is shown in Fig. 12.

Fig. 13 shows the mean hemispherical candle-power distribution of a 220-volt burner equipped with a reflector and no globe, operating at 4.57 amperes and 149 volts on the burner, the curve in this case being taken in a plane perpendicular to the burner axis.

Fig. 14 shows the distribution of a similar type of burner equipped with similar reflector and enclosed in a clear glass globe. The curve A is in a plane perpendicular to the burner axis and curve B is in a plane parallel to the burner axis, while curve C is the mean of curves A and B.

By the use of a different reflector and a light opalescent diffusing globe, the results shown in Fig. 15 are obtained, which in a plane perpendicular to the axis gives a much wider distribution.

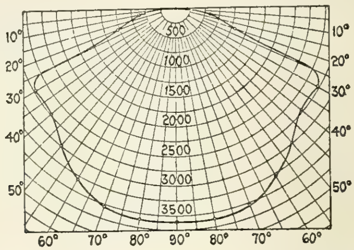

Fig. 13.—Hemispherical candle-power distribution of 220-volt quartz burner equipped with reflector but no globe.

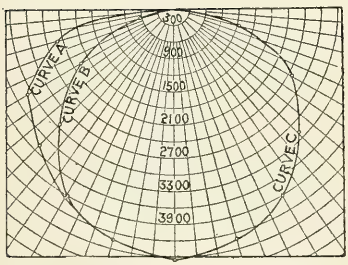

Fig. 14.—Hemispherical candle-power distribution of 220-volt quartz burner equipped with reflector and clear glass globe.

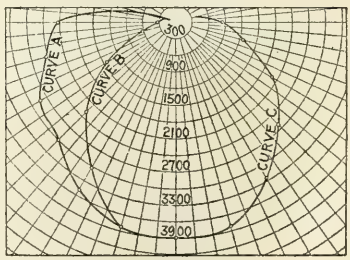

Fig. 15.—Hemispherical candle-power distribution of 220-volt quartz burner equipped with reflector and diffusing globe.

A vertical type of lamp has been developed in order to give a maximum intensity of about 45 deg. for use in street lighting and yard lighting.

DESCRIPTION OF OUTFITS.

The quartz outfits as manufactured conform in external appearance to the ordinary enclosed arc lamps, those for 110 and 220 volts being somewhat shorter, while the 550 volt lamp is

slightly longer. Fig. 16 shows the external appearance of the 220 volt lamp while Fig. 17 is a 550 volt lamp.

The interior mechanism is extremely simple, consisting of a resistance coil to provide backing and to allow adjustment for the different line voltages, an inductance coil to aid in steadying the arc and a small solenoid to operate a plunger for tilting and starting the burner, and a small cutout coil in the 220 and 550 volt lamps for cutting out the tilting coil after the burners start. In the 110 volt lamp no cutout coil is provided and the induction and tilting coils are combined. In this lamp at the non-operating position, the mercury in the burner makes contact between two electrodes and by tilting the metallic circuit is broken and the arc is formed, the burner being always held in this position during the running of the lamp. In the other types before starting there is no metallic connection between the electrodes and when the current is applied, the mercury streams along the tube making contact, the arc starts and the cutout is then energized cutting out the solenoid, which allows the burner to drop back to the position of rest.

The operation of the 550 volt lamp is similar to that of the 220 volt, but it is provided with extra resistance placed at the top to take up the increased line voltage at the start.

Fig. 18 shows schematically the wiring for the 220 volt lamp. The general characteristics of the different lamps are shown in the following table:

Nominal voltage supply	Range	Burner volts	Current	Total watts
110	100-125	85	3.8	418
220	200-250	165	3.3	725
550	450-625	345	2.0	1,100

The above lamps are provided with suitable reflectors and equipped with clear globes where lamps are hung high or with opalescent globes for low mounting.

Besides the above mentioned outfits, there is also manufactured a laboratory outfit as shown in Fig. 19 where the burner is placed in a suitable holder and started by hand. Globes are not furnished with this lamp, as it is intended simply for the application of the ultra-violet rays which are present and not for

commercial illumination. Special outfits for different photographic applications are also being made.

APPLICATION OF THE MERCURY-VAPOR QUARTZ LAMP IN THE LIGHTING FIELD.

On account of its extremely high efficiency, the quartz lamp has rapidly found a wide application in the lighting field, though its color up to the present time has limited it to industrial work entirely.

The immense amount of flux obtained by the use of the 220 volt lamp has permitted the lamps to be placed in shops over the cranes where the height of roof trusses approaches 100 feet and yet has given excellent floor illumination.

On account of the elimination of trimming, lamps can be placed in inaccessible places without the necessity of special runways or platforms being constructed. Furthermore, if burners are adjusted properly at the start a reasonably wide variation of line voltage is permissable and the lamps can be operated from power circuits without experiencing any difficulties.

A few typical installations showing the different classes of work for which quartz lamps are used with satisfactory results and the relative consumption of current is given below:

	Lamps	Sq. ft. per lamp	Watts per sq. ft.	Height (feet)
Boiler shop	4	4,500	0.16	48
Plate glass manufacturer	4	2,330	0.35	35
Mechanical engineering laboratory	7	1,120	0.69	35
Locomotive repair shops	12	2,992	0.25	52
Heavy machine shops	3	3,270	0.23	45
Foundry	2	2,400	0.29	42
Paper mill machine room	2	2,000	0.35	30
Steel construction	72	4,166	0.17	40
Heavy machine shop	2	2,500	0.28	19
Drill hall	8	3,900	0.20	30-40
Foundry and erecting shop	96	3,600	0.21	35-50
Steel punching shop	9	6,880	0.11	35-40
Engine room	3	2,541	0.39	44
Turbine room	7	2,857	0.25	46
Moulding	3	5,700	0.16	35
Engine room	2	3,600	0.22	40

Besides the above, the quartz lamps have also been used successfully for the lighting of railroad repair shops, smelting works,

piers, steel works, locomotive works, stamping works, car works, ship building plants, automobile plants, rifle ranges, and in fact for all industrial operations where the necessary height, required for good distribution can be obtained.

A recent test between quartz lamps and four different types of long burning flame arc lamps, all mounted so as to cover the same amount of floor space and at the same heights gave the following results:

	Quartz lamps	Arc lamps A	Arc lamps B	Arc lamps C	Arc lamps D
Height above reading plane	42′	42′	42′	42′	42′
Average foot candles......	1.37	0.75	1.01	0.79	0.63
Total effective lumens	17536	9600	12928	10112	8058
Total watts measured	3197	2266	3335	3128	2645
Lumens per watt	5.49	4.24	3.88	3.23	3.05
Watts per lumen	0.182	0.236	0.257	0.309	0.328
Relative efficiency........	100%	77%	71%	59%	56%

The above tests were made in a shop where walls, roof and floor were all black and reflection did not add in any way to the results obtained.

For exterior lighting, the quartz lamp has rapidly gained favor, particularly in yard lighting. The best results are obtained by placing the lamps on poles at heights ranging from 40 to 70 feet (12.19 to 21.34 m.)

Fig. 20 shows the illumination from one quartz lamp in two planes, compared with the illumination of a 6.6 ampere arc lamp. The quartz lamp in this case being mounted 66 feet high with the arc lamp 21 feet. It will be noted that with the quartz at this extreme height the illumination is well over 0.01 foot-candle for a distance of over 200 feet (60.96 m.) away from the lamp. This installation is typical of a number where lamps have been adopted for this class of work, and the satisfactory results obtained present an extremely wide field for the use of this lamp.

A number of small installations of street lighting with quartz lamps have been made in coöperation with business men's associations, but on account, at the present time, of the non-introduction of a series or an alternating current lamp, this field has been extremely narrow. However, with the advent of these two latter types, there is no doubt that the quartz lamp will become exceedingly popular for street lighting.

Lamps hung 40 feet (12.19 m.) above the sidewalks give fairly even illumination over thoroughfares of 60 to 80 feet (18.29 to 25.38 m.) wide, and the color does not prove objectionable along the sidewalks as it is offset by the yellow light of the window illumination. Moreover, the difference in color between the lamps and the window lighting appeals to the merchant as it offers a contrast for the display of his goods, which is not as marked with the use of the ordinary yellow street illuminant.

Recent experiments made by the United States Light House Board have demonstrated that for use in ordinary light house lenses, the quartz lamp has a greater multiplying factor than any of the other illuminants used for this purpose. Moreover, on account of the color of the lamp, it offers an illuminant entirely

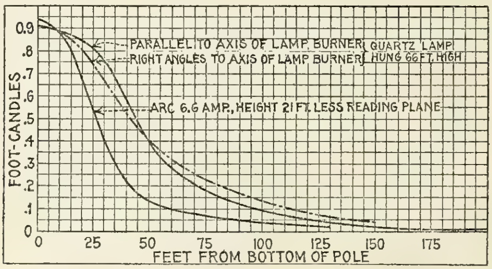

Fig. 20.—Horizontal illumination derived from a 220-volt quartz lamp.

distinct from all others and obviates confusing a fixed white light with shore lights. Quartz lamps are now being used to illuminate the memorial tower of the Seamen's Institute in the lower end of New York City and the light, which is the only green one on the coast, has been designated and charted as an official fixed light by the light house department.

Naturally with a high efficiency lamp, the question of maintenance is a very pertinent one. Burner replacement is practically the only item that enters into this figure, and when a burner loses its vacuum, or is even broken, it is not necessary to purchase an entirely new burner, as the first one can be repumped. There is always some scrap value allowed for an old burner. As far as can be ascertained from the figures at present obtainable, the cost per 1,000 burning hours will average some-

where between $4.00 and $5.50 for the 220 volt lamp. The average life is about 2,500 to 3,000 hours before repumping is necessary, and burners can be repumped about three or four times. Burners have been in service to date which show a life of over 8,000 hours and there is no doubt that with the new type of seals they will be able to approach the life of standard tube lamps, some of which have run as long as 60,000 hours.

QUARTZ LAMPS FOR PATHOLOGICAL AND OTHER PURPOSES.

While the quartz lamp has been developed primarily as an illuminant, on account of the richness of the lamp in the ultra-violet ray spectrum, there is no doubt that the new lamp will find a wide field in pathological, physiological, photographic and industrial chemical work.

As will be seen by referring to Fig. 11, the wave-lengths in the ultra-violet spectrum extend to about 222 when the lamps are operated without a glass globe. The rays from 222 to 270 fall within what are known as the abiotic rays and effect destruction of organic matter. Those from 250 to 270, however, are only about one-hundredth as destructive as the balance. Cernovodeneu and Herni have made numerous experiments to determine the effect of these rays from quartz lamps on different microbes, and their results show the following:

That the bactericidal action decreases more rapidly than the square of the distance, and for short distances the 220 volt lamp is five times as active, as the 110, while for greater distances (60 c. m.) it is ten times as great.

The action is independent of temperature varying from 0°-500° C. and is produced with nearly the same speed in the absence of oxygen as in air.

The length of life of different microbes varies from 5 to 10 seconds for staphylococcus aureus to 30 to 60 seconds for bacillus megatherium.

By interposing a sheet of clear glass 1 mm. in thickness the bactericidal action is diminished, 3 to 5 hours being necessary in place of 15 to 20 seconds. The interposition of sheets of mica or viscum also tends to retard the sterilization process.

With the results as stated above, it is evident that a large

field for the use of the quartz lamp would be its application for the sterilization of milk and water.

While no plants on a large scale have been constructed in this country for this purpose, in France and Italy there are now a number of small towns whose water supply is being completely sterilized by the use of the quartz lamp.

The apparatus used for this purpose consists of a cast iron container, as shown in Fig. 21. The quartz lamp is mounted in a box with windows of quartz which is placed so as to come into contact with the water to be sterilized. By the use of baffle plates the water is brought under the influence of the ultra-violet

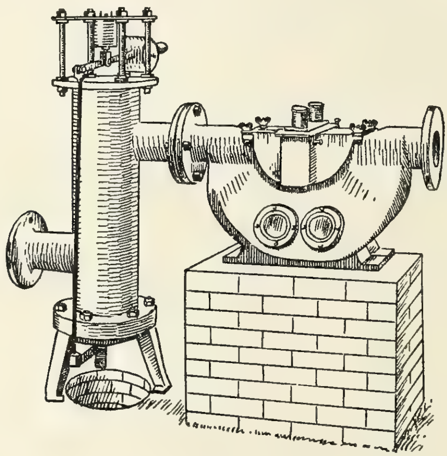

Fig. 21.—Exterior view of large water sterilizer equipped with quartz burner.

rays three distinct times. The interior arrangement of the apparatus is shown in Fig. 22. An electromagnet is placed in series with the lamp and if for any reason the lamp goes out, the magnet releases and opens a drain valve and no water can pass out excepting that which has been sterilized. The water admitted to the sterilizer must be free from dirt and in most installations a filter plant is operated in conjunction with the sterilizer. The outfit as shown will sterilize perfectly 130,000 gallons of water per 24 hours for about 725 watts per hour.

A smaller outfit which will sterilize about 130 gallons of water per hour is also being used in hospitals, hotels, etc.

While the sterilization of water is efficient and can be worked out with simplicity for commercial use, the application of the ultra-violet rays for the sterilization of milk offers some difficulties and this has retarded the development of a commercial milk sterilizer. Milk in bulk is opaque to ultra-violet rays, which prevents the sterilization from being fully performed. This objection, however, has been overcome by running the milk over drums and also streaming it over plates. Ayers and Johnson found that by using one 220 volt lamp, at a distance of four inches from a layer of milk 0.1 mm. in thickness, revolving over drums making 20-24 r. p. m. which gave an exposure of about two seconds, they were able to reduce bacteria materially, the

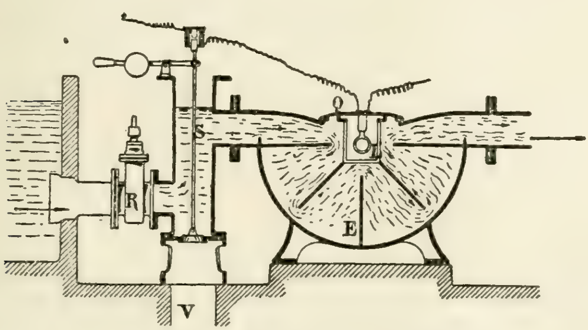

Fig. 22.—Interior view of water sterilizer.

least reduction being found in one control of milk which had 10,200,000 bacteria per cc. before sterilization and 38,000 afterwards. The temperature of the milk during these tests never exceeded 38° C.

Numerous experiments are now being carried on in different classes of industrial work to determine the efficiency of the quartz lamp, in processes where sunlight is now used.

Among these may be mentioned the fixation of patent leather; where at present the leather after being varnished and baked is exposed to the sun for a period of at least ten hours. By using lamps for this purpose, the time has been cut to three hours with similar results. As the best results can only be obtained under conditions where the atmosphere is clear and fairly cool, it will

be evident that an extremely wide field has been opened in this respect for the quartz lamp.

The testing of the permanency of colors by the use of ultra-violet rays is also being carried on extensively. By submitting samples of color dyes to the influence of the lamp for certain lengths of time a manufacturer can determine rapidly whether the color is fast or not. To accomplish this by sunlight, it may be necessary to expose the sample about 72 hours on clear days, whereas with the quartz lamp results have and can be ascertained within a few hours. Some manufacturers find it difficult to test colored silk goods except during the early summer months and must depend upon these tests in planning their winter work. It follows from this that the bleaching of vegetable fabrics such as cotton, or flax fiber or paper stock may be successfully accomplished. Experiments conducted along these lines bear out this conclusion. However, it has been found necessary first to saturate the material with a weak alkali solution before submitting the same to the action of the lamp, after which cotton cloth can be thoroughly bleached in from a half an hour to an hour's time.

The bleaching of white flour offers another opportunity for the introduction of the quartz lamp. The present process of using ozone has been condemned by the government on account of the lessening of food values in the flour. The same results occur if the flour is treated without carrying off the ionized air generated by the quartz lamp, but this can be overcome by confining the lamp in a quartz box.

Still another industrial process is the "deblooming" of hydrocarbonate oils, vegetable oils and paraffine. This process is carried on by exposing the oil in shallow uncovered tanks to the sun rays for a number of weeks. Tests have demonstrated that the same results can be obtained by the exposure to the quartz lamp in a much shorter period of time.

The application of the lamp for all of the above processes is rapidly being worked out and it is only a question of whether the time saved is sufficient to offset the expense, that prevents the immediate equipment of several plants for the operation of the different processes. As with all new methods it is necessary to

thoroughly convince the manufacturer before he will revise his former manner of obtaining results.

From the physiological standpoint, the lamp is much simpler and cheaper to operate than the so-called Finsen rays, and it is being used in hospitals for the treatment of lupus and other skin diseases.

For photographic work the lamp can be substituted for numerous types of arc lamps consuming 15 to 30 amperes with high carbon costs as in contact printing work, and all other classes of photographic printing.

For high class portraiture work, a quartz lamp outfit has recently been designed which is particularly adaptable for use in connection with either the ordinary glass skylight, or a mercury-vapor tube skylight for making window pictures and for obtaining Rembrandt effects.

The burner in the outfit is equipped with a parabolic reflector enclosed in a metal box with diffusing glass and the lamp can be adjusted for any height and for any direction, so as to give spot light effects.

In moving picture studios the lamps are being used in conjunction with the standard tube lamps to obtain special effects, and for this class of work they are replacing high current arc lamps.

The cylindrical blue printing machines offer another application and a special type of quartz lamp is being adapted for this purpose.

With the application of the quartz lamp for commercial lighting, sterilizing, chemical, pathological and photographic purposes there is no doubt that the development will be very rapid and that another year will find it extensively used throughout the country.

The author wishes to express his thanks to Dr. Frederick G. Keyes for his preparation of a number of the curves used in this paper.

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DISCUSSION.

Mr. Percy W. Thomas (Communicated): Mr. Evans has given an unusually well balanced summary of the interesting features of the mercury-vapor lamp with quartz container. The explanations and the numerical data given are naturally of very great interest to those who are interested in illumination. The increase of the efficiency and the decrease of the physical size of the quartz tube in comparison with the ordinary tubes of mercury-vapor lamps alter its commercial characteristics in such a way as to greatly broaden the field of the mercury-vapor lamp. For interiors of relatively low height which are utilized for close work, such as drafting, the low pressure type with low brilliancy and relative freedom from shadows is especially favorable. Out doors or in high spaces where rough work is in order, the small size, simplicity and higher efficiency of the high pressure mercury-vapor lamp ordinarily give it the preference. In fact there are very few cases of industrial lighting where one or the other of these lamps cannot be more advantageously used than any other type of illuminant, with the exception of cases where the color quality renders them unsatisfactory.

The commercial development of the high voltage lamp has been closely linked with the development of practical methods of manipulating quartz in large quantities. It is an interesting fact that Peter Cooper Hewitt in his early work developed a high

pressure lamp having characteristics surprisingly close to the present quartz lamps. Hewitt, however, was handicapped in offering a commercial lamp by the difficulties of making suitable containers on a large scale. On the other hand, it is possible, as Hewitt showed, to utilize glass in such lamps to a far greater extent than might be supposed possible by a person who had not made the trial. It is entirely possible to operate a lamp in a glass container as distinguished from a quartz container with a pressure even as high as atmospheric pressure or perhaps higher which is not far from the pressure at which present commercial quartz lamps are operated and this in spite of figures quoted by Mr. Evans in his paper to the effect that Küch has calculated that the temperature in the center of the arc of a quartz lamp is between 4,000° and 6,000° C. Whatever the arc temperature may actually be, an ordinary thermometer measurement will show that the temperature of the container of a quartz lamp is far less. It may be as low as 300° C. near the electrodes. This explains why it is possible, as was done by Hewitt in a somewhat similar way, and at a later date by Bastian in England, to operate high pressure lamps in glass containers. The figure given by Mr. Evans that 1,500° C. will soften quartz shows clearly that the 4,000° to 6,000° offered by Küch as the temperature of the arc is not and does not indicate the temperature assumed by the actual tube. However, in ordinary installations, it is necessary to have a wide margin in operating temperature over the softening point of the container and quartz is the best material so far proposed for this purpose.

The curves of efficiency shown in Figs. 1 and 2 of the Evans paper should perhaps receive some comment as they have appeared elsewhere in literature as indicating measurements by Mr. Küch on the efficiency of his quartz lamp. The point I have in mind is the fact that efficiency depends upon so many conditions and assumptions. For example, taking a lamp designed to operate at high pressure at a good efficiency and then operating this lamp at a low pressure and measuring its efficiency would hardly give a fair comparison of the efficiency of a high pressure and a low pressure lamp. It would be fairer to compare the efficiency of the lamp adapted for high pressure with the efficiency of a lamp designed for low pressure. When this fact is

recognized it will be clear that no curves of efficiency like that of Fig. 2 should be plotted without determining for each of the intermediate points between the points marked L and H the proportions and best conditions of a lamp designed to operate at that particular pressure and then determining its efficiency. In all probability no such method was utilized in deriving this curve. If, as may perhaps be supposed, all the efficiency measurements are made upon one type of lamp the result might be compared to a curve indicating the variation of efficiency of generators with the voltage by taking a high voltage generator and measuring its efficiency at various voltages from zero up to its proper voltage. Broadly speaking, such a curve would obviously be of no value as a measure of the effect of voltage on efficiency.

One of the most significant features of the quartz lamp as pointed out by Mr. Evans is its rich output of ultra-violet rays which are suitable for so many chemical and similar operations. While this field will be slower in its development, the quartz lamp offers a new instrument for the moulding of nature's laws to the production of useful products.

Mr. L. C. Porter (Communicated): On the eighteenth page it is stated that "Recent experiments made by the United States Light House Board have demonstrated that for use in ordinary light house lenses, the quartz lamp has a greater multiplying factor than any of the other illuminants used for this purpose."

As I understand it, the term "multiplying factor" as here used, means a ratio between the maximum horizontal candle-power of the lamp alone and the maximum candle-power of the beam projected by the lens and lamp combined. In this case the multiplying factor depends to a very large extent upon the concentration of the light source. The smaller the light source, the higher will be the intensity of the beam, with a corresponding increase in the multiplying factor. With the new concentrated filament tungsten lamp very high multiplying factors are obtainable.

THE ILLUMINATION OF STREET RAILWAY CARS.*

BY L. C. PORTER AND V. L. STALEY.

Synopsis: In some of the recently built railway cars, bare carbon lamps have been supplanted by tungsten lamps equipped with suitable reflectors. Figures are given to show that this change has not only afforded more effective and hygienic illumination, but has reduced the energy consumption within a period of a few months sufficient to pay for the extra cost of the reflector equipments. Over longer periods of operation, the authors state, the possible saving will eventually warrant the cost of rewiring old cars for tungsten lamps and reflectors. An illumination of 2.5 to 3 foot-candles is required on the average passenger's reading plane—45 degrees 3 feet above the floor. With railway tungsten lamps of the present efficiencies this intensity may be obtained at an energy expenditure equivalent to 10 watts per linear foot or 1.25 watts per square foot of floor area. Wiring diagrams, curves showing the candle-power variations in carbon, gem and tungsten lamps caused by voltage fluctuations; the results of a number of tests, and views of lighted car interiors are included in the paper.

Until very recently little has been done towards improving the lighting of street cars. Modern methods of efficient and economic illumination have been in vogue in almost every other phase of industrial, public and private enterprise. So far, however, the great majority of street cars are lighted with the clear bare carbon lamps. While these lamps may have given sufficient light for reading purposes when a car system was originally built, they very soon became inadequate, due to increase in street railway schedules, growth of the community, etc. Even under the best of conditions the lamps as installed without shades or reflectors did not afford efficient utilization of the generated light; nor was the lighting free from annoying glare. At certain rush hours there is a drop in voltage, which with carbon lamps produces a marked decrease in the illumination. These rush hours, while of comparatively short duration, occur at a time when the railway companies are attempting to serve the greatest number of people. During this time the motors are not seriously affected by the low voltage; on the other hand the candle-power of the lamps drops considerably. This is a very serious condition, particularly on account of the number of customers being served. The railway companies are not justified in going to the expense of installing additional feeder capacity to take care of the lighting alone. There has been, therefore, need of a lamp of better inherent regulation—one which would maintain nearly constant candle-power over fluctuating voltage. In addition to these circumstances the rising standard of illumination

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throughout the country has made it desirable to increase the lighting of street cars without, if possible, increasing the power consumption.

When the tungsten filament lamps were produced, it was recognized that they had characteristics which made them highly advantageous for railway service. Their increasing resistance with increase of voltage was a large advance toward steady illumination with fluctuating voltage, and their high operating efficiency enabled a large increase in illumination with actual reduction in energy consumption. However, the tungsten pressed filaments at first manufactured, were too fragile to withstand the severe vibration of street car service. The construction of this lamp has been so improved that it now gives the long life of 2,000 hours in the laboratory and 1,200 to 1,500 hours under street car service conditions. The strength of the lamp is such that it withstands even surprisingly bad operating conditions. With its high efficiency, in the neighborhood of 1.25 watts per candle, it has practically eliminated the use of the tantalum lamp.

The high intrinsic brilliancy of the clear bare tungsten filament lamp, together with an ever-increasing demand for efficiency, has brought about a study of methods of application of this type of lamp to street railway service. A little over two years ago Mr. G. H. Stickney of the General Electric Company, with the co-operation of Mr. E. W. Holst of the Bay State Street Railway Company, made a study of various methods of street car lighting and conducted some very thorough service tests to back up theoretical calculations.

METHODS OF INSTALLATION.

The first lamps used for car lighting were 16 candle-power, 4-watt-per-candle, S-19 bulb carbon lamps. There were two general methods of installing these units. Either they were located in groups down the center of the car, or else scattered as individual units over center and half decks. Occasionally the groups of lamps were placed under flat steel porcelain enamel reflectors which, while they undoubtedly added somewhat to the downward illumination, were of no assistance in shielding the eyes of the passengers from the glare of the bare lamps. The lamps were burned vertically; they were also mounted horizontally on the

half decks. In each case lamps of one-fifth the average trolley voltage were wired in series of five. There were usually three, four or five circuits of lamps, the lamps in the car body being wired on alternate circuits, so that the failure of one of the lamps would not cut out all the light in one section of the car. In many cars illuminated signs were used, not infrequently one or two lamps being used for each end sign. A frequent arrangement was to have the four sign lamps and the headlight lamps on one circuit. Where but two sign lamps were used they were usually put in series with lamps in the car body. In some of the later cars transparent signs were used. These were usually lighted with individual lamps or by the general illumination in the car body. Where a fairly powerful headlight was desired, the wiring was occasionally arranged to connect two series circuits of four lamps each in parallel through the headlight, and a headlight lamp was used having double the candle-power of the lamps in the car body. In order to enable its use with a lens or parabolic reflector, this lamp had a concentrated filament. For interurban cars, arc headlights operated on a circuit by themselves through resistance were frequently used.

The first change in the lighting of the car bodies consisted in replacing the carbon lamps, lamp for lamp, with 23 or 36-watt tungsten lamps. This brought about an increase in the illumination at normal voltage of 6 per cent. where 23-watt tungsten lamps were used and 66 per cent. where 36-watt are used. At 80 per cent. normal voltage there was an additional increase of 43 per cent. over the carbon, due to the better regulation of the tungsten lamps. This gain was obtained at a power saving of 65 and 44 per cent., respectively, depending upon whether 23 or 36-watt lamps were used.

Due, however, to the very high intrinsic brilliancy of the tungsten filament in the lamps, the glare was increased, so that it became quite evident. It was also realized by illuminating engineers from tests which had been conducted on various installations in buildings, that a large percentage of the total light flux generated by the lamps was being wasted. This was due to the fact that much of it fell on dark walls and headlining, and was largely absorbed or passed out of the windows. In other words

the lighting with clear bare lamps was neither comfortable nor efficient. This led to a study of possible reflector equipments.

Investigation showed that the use of scientifically designed reflectors giving the so-called intensive type of distribution would not only largely reduce glare, but also raise considerably the efficiency of light utilization of the installation. It was found that two principal reflector locations could be used to advantage; one being the use of a single row of lighting units down the center line of the car, *i. e.,* center deck lighting; the other a double row of units, one down each half deck. As far as uniformity of distribution, absence of sharp shadow and efficiency were concerned, either method gave equally good results. The center deck system, however, had the advantages of fewer fixtures to install, less wiring, less cleaning and maintenance, the use of larger, hence stronger and less expensive, per-candle-power, lighting units. That is to say, both initial installation and maintenance costs were lower with this system. In the center deck system lighting units were also located higher and a little further out of the direct line of vision of seated passengers. For both systems, the lamps were wired on alternate circuits.

Where center deck lighting was used it was found that either two circuits of 56-watt tungsten lamps, or one of 94-watt lamps equipped with intensive type reflectors gave ample illumination. In the former arrangement six lamps were located in the car body, one on each platform, one in each end sign and one in the headlight. Where two sign lamps were advisable at each end, 28-watt half-voltage lamps were used, two of these in series being equivalent to one 56-watt full voltage lamp. This is equivalent to two circuits of five 56-watt lamps each.

Where 94-watt lamps were used four were located in the car body and one on each platform, the forward platform lamp being extinguished. An auxiliary circuit of 23-watt lamps was installed for signs and the headlight. As there is but one circuit of lamps in the car body with this arrangement, the failure of one lamp leaves the car in darkness temporarily. To facilitate locating the burned-out lamp a selector switch is used, by means of which the conductor can quickly bridge an extra lamp (usually located on the platform) across each lamp in the car body until

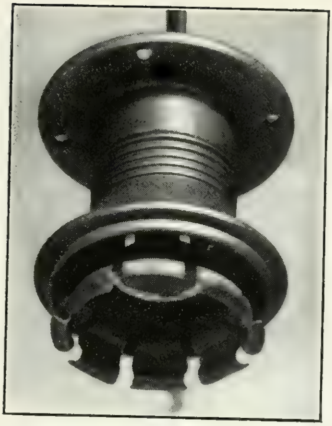


Fig. 1.—A special lamp socket and shade holder designed for railway cars.

Fig. 2.—A 34-ft. car equipped with tungsten lamps in prismatic reflectors.

Fig. 3.—A 34-ft. car lighted with 56-watt tungsten lamps equipped with prismatic reflectors.

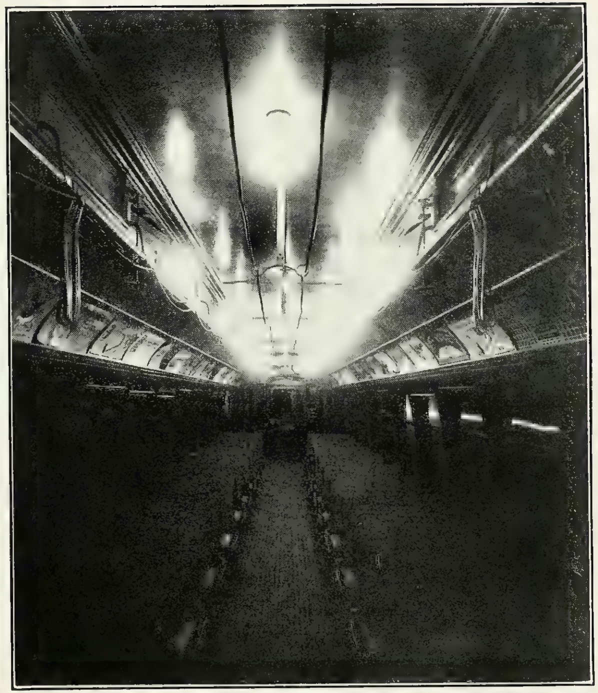


Fig. 4.—A 34-ft. car equipped with 21 64-watt bare carbon lamps.

the burned-out lamp is located. The extra lamp then takes the place of the burned-out unit until it can be replaced. This system requires the use of more wire and a special switch. Due to the relatively wide spacing of the four units in the car body the illumination is not so even as with the 56-watt system.

A few systems were found where the cars carried no sign lamps or incandescent headlights. These cars used an arc headlight and depended upon the illumination of the interior of the car to light their transparent signs. This type of car has been very satisfactorily lighted by the use of two rows of 36-watt tungsten lamps equipped with intensive type reflectors located on the center deck twelve inches to each side of the center line.

With half deck lighting, 23 or 36-watt lamps are usually used, equipped with intensive type reflectors. In either center or side deck lighting the lamps are usually wired on alternate circuits.

The question of the intensity of light required is one which has also been given considerable attention. It has been found that from 2½ to 3 foot-candles were desirable on the reading planes (45 degrees three feet above the floor), *i. e.,* the position in which the average reader holds a paper. With either center or half deck lighting where efficient intensive type reflectors are used, approximately 82 lumens per running foot of car body will supply this illumination. With the present efficiencies of the railway tungsten lamps this corresponds to about 10 watts per running foot, or 1.25 watts per square foot of floor area. Indirect or semi-indirect lighting systems were also tried. These required the use of a very light headlining and even then it was necessary to largely increase the energy required for direct lighting systems; glare, however, was practically nil. The energy required together with the necessity of frequent cleanings of both reflectors and headlining for satisfactory service, and the low head room in street railway cars, makes the direct lighting system usually preferable.

There are many types and styles of reflectors on the market both for direct and indirect lighting. Many of these are perfectly satisfactory for car use, choice of the particular type being dependent upon the artistic taste of the individual making the selection. A few general considerations, however, were found applying to all types.

FIXTURES AND REFLECTORS.

"Safety First" is a slogan which is being largely followed by the most progressive roads to-day. The passengers in a street car must be protected against accident. With the addition of glass reflectors to the car, comes the need of some form of special holder which would absolutely insure the reflector against jarring loose and falling. Several types of holders have been designed to meet this demand. Of these, two have proven very satisfactory. Both of these utilize a cone-shaped wedge which screws down, thus forcing springs against the neck of the reflector and locking them there. One holder uses spring fingers; the other a coiled helix to grip the reflector neck. These holders also contain the lamp socket and can be either screwed or bolted to the car.

Another holder is under construction in which a spring is used for the socket of the lamp shell, similar to the marine type socket. This will absolutely prevent the lamp from shaking loose. These holders are made both form "O" and form "H" to accommodate the small and large lamps, respectively.

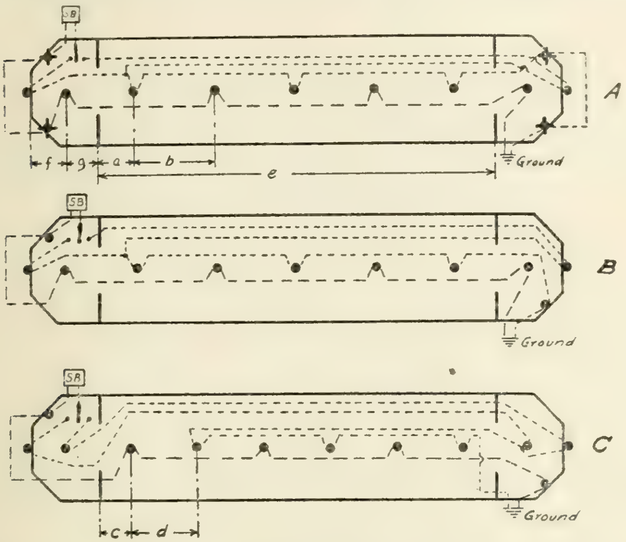
Even the very best holder requires the use of a good rugged reflector. These should be made of fairly heavy glass to assure their strength. For direct lighting either clear prismatic or opal glass reflectors will give excellent service. If satin finished or sand blasted reflectors are used, more frequent cleaning is necessary to maintain their efficiency. For the average car having a ceiling of seven to eight feet and a width of eight feet, reflectors giving the intensive type of distribution were found to give the most satisfactory results. The intensive type of distribution was found best because it delivered the greatest percentage of the total generated lumens, or light flux, where it was most needed, namely, on the passengers' reading matter. Opaque reflectors are not recommended for direct lighting systems, due to the dark, gloomy appearance they give the ceiling. For indirect lighting, however, they are excellent.

Reflectors should be used which have sufficient depth to prevent the lamp filament from being visible to any except the passengers almost directly beneath the lighting units. Any system of semi-indirect or indirect lighting requires a very light head-

lining, which should have a mat surface. If a glossy surface is used the direct reflection of the lamp filaments may result in considerable objectionable glare.

INTERIOR CAR FINISH.

The question of the color and finish of the interior of a street



*A- Car wired for burning both platform lamps and two markers on each platform. 5 lamps in car body.
*B- Car wired for burning both platform lamps and one marker on each platform. 5 lamps in car body.
C - Car wired for burning rear platform lamp only. 6 lamps in car body.
● - Denotes a 56 W. Railway Tungsten Lamp. Full Voltage
✦ - Denotes a 28 W. Railway Tungsten Lamp. Half Voltage

Spacing	Length of Interior of Car Body "e"						
	e = 28 ft.	e = 30 ft.	e = 32 ft.	e = 34 ft.	e = 36 ft.	e = 38 ft.	e = 40 ft.
a	2 "	3 "	2 "	3 "	*2¼ "	*3¼ "	*2 "
b	6 "	6 "	7 "	7 "	*3½ "	*3½ "	*4 "
c	1½ "	2½ "	2¼ "	2 "	3 "	2¾ "	2½ "
d	5 "	5 "	5½	6 "	6 "	6½ "	7 "
f = g	in all cases where practical						

* Three circuits recommended for cars over 34 ft.—10 lamps in car body.

Fig. 5.—Wiring diagrams for trolley cars equipped with 56-watt railway tungsten lamps and prismatic reflectors.

car is one which warrants a great deal more attention than it has so far been given. Whether the lighting system be indirect,

semi-indirect or direct, the finish of the car has a very appreciable effect not only on the resultant illumination, but also upon the passengers' comfort. A light color finish has several advantages. It gives the car a cheerful appearance and in this manner serves indirectly as an advertisement for the railway company. It makes the contrast between the lighting units and the

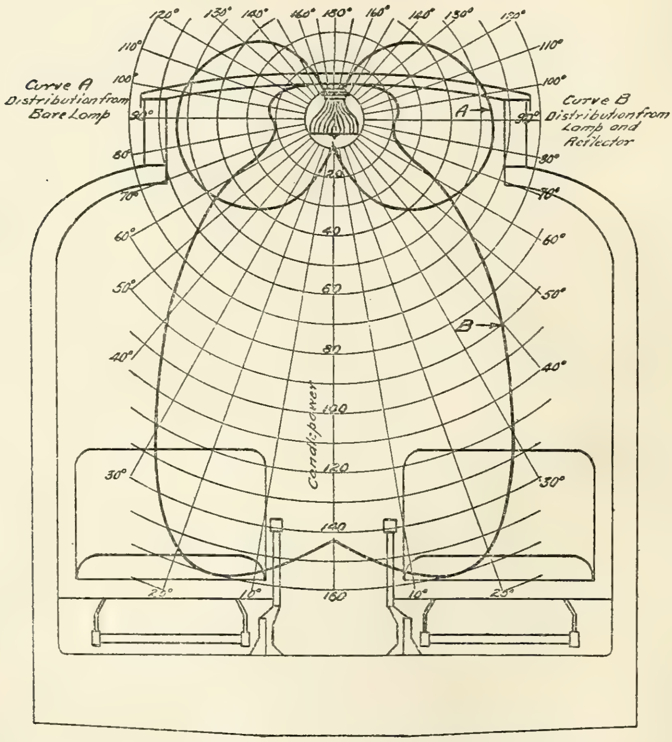


Fig. 6.—Light distribution from a clear bare 56-watt railway tungsten lamp, and from same lamp equipped with an intensive 40-watt clear prismatic reflector.

rest of the car less conspicuous, thus making the illumination more pleasing. Of still more importance, however, is the fact that with a light finish a considerably higher percentage of the light is reflected down on the reading plane.

Tests have shown that with the common dark yellow finish of street cars the efficiency of light utilization is approximately 15 per cent. where no reflectors are used, and 30 per cent. with a

good direct reflector system. In one car in which the finish of the walls and ceiling was white, as high as 60 per cent. utilization efficiency was obtained. While it is in most cases impractical to use white finish, a great deal of improvement is possible over present practise. Upon the finish of the car depends, to a certain degree, the amount of light that it is necessary to furnish; this in turn involves the type of illuminant used.

LAMPS.

The first incandescent lamps used were the 16-candle-power, 64-watt carbon lamps. They were especially selected for the amperes to burn in series. Later the 54-watt gem or metalized carbon lamps came into considerable use. These were followed by the 40-watt tantalum lamp, and the present four sizes of tungsten lamps.

On a system having considerable voltage variation between different points, lamps should be chosen whose voltage approximates the average voltage of the system, taking into account the time element and distance factor. Tungsten lamps have several very decided advantages over carbon lamps. Due to their positive temperature coefficient, their candle-power changes less on fluctuating voltage. Thus on low voltage at the ends of a long line, during the rush hours, or when the car is ascending a hill, they will still give considerable illumination, when carbon lamps may be practically extinguished. Their power consumption per candle-power is very much lower than carbons and their light is whiter.

Improvement in the method of drawing tungsten wire, of course, resulted in improved strength of tungsten lamps. This together with advancement in the methods of mounting, makes possible the use of these lamps under the severest conditions of street car service. The lamp manufacturers are now able to draw tungsten wire to exact diameter. This assures the fact that in series operation all lamps will operate at the same efficiency. Lamps of exact amperes instead of those covering a range can be supplied; thus the railway companies can be sure of obtaining at any time lamps which will operate satisfactorily in series with those already installed, resulting in uniform brilliancy.

It is present practise in the manufacture of tungsten railway

lamps to use one size wire for each size lamp, regardless of voltage, *i. e.,* the filament diameter is selected for lamps of a certain wattage rating at 115 volts and cut longer or shorter, depending upon the voltage desired. Hence, the wattage of the lamps will be slightly higher for voltages above 115 and slightly lower below that figure; but this variation is not great enough to be objectionable. Street railway lamps are operated at a slightly lower efficiency than those for regular multiple service, chiefly to obtain a long life necessary to justify their higher first cost with very low power rates.

Four tungsten lamps have been especially developed for railway service, namely:

23-watt S-19 bulb operating at 1.34 watts per candle
36-watt S-19 bulb operating at 1.34 watts per candle
56-watt S-21 bulb operating at 1.20 watts per candle
94-watt S-24½ bulb operating at 1.20 watts per candle

All four types are giving a laboratory life of 2,000 hours and are so rated in the manufacturer's data books. This life under service conditions may be estimated at 1,200 to 1,500 actual burning hours. From these figures it is easy to see that these lamps are economical. Take, for example, a thirty-four foot car equipped with twenty-five lamps. If 64-watt carbons are used the following figures are obtained:

Renewals per hour; cost of lamps at list price of 14c. $= \frac{14c. \times 25}{1,200 \text{ hrs.}} = \$0.0029$

Cost per hour of energy delivered at the car,

1,600 watts at 1c. per kw-hr., $\frac{64 \times 25 \times 1c.}{1,000} = 0.0160$

Total $0.0189

If 23-watt tungsten lamps are used by similar calculation the results will be:

Lamp renewals.............................. $\frac{35c. \times 25}{1,200} = \$0.0075$

Energy.................................... $\frac{23 \times 25 \times 1c.}{1,000} = 0.0057$

Total $0.0132

This shows an actual net saving of $0.0057 per car hour, in addition to obtaining better illumination. If ten 56-watt tungsten lamps and reflectors are used the saving becomes $0.0096 per

car hour, while the useful illumination is practically doubled. This saving in 1,466 hours' operation would pay for the eight reflectors and eight special holders necessary. Thus, after five months' operation (at ten hours per night) the equipment will have paid for itself and from then on a clear saving of $0.0096 per hour would accrue to the company, to say nothing of the advertising value of well lighted cars. This saving on five hundred cars (assuming 33⅓ per cent. of them are lighted on an average of ten hours per night) amounts to $5,670

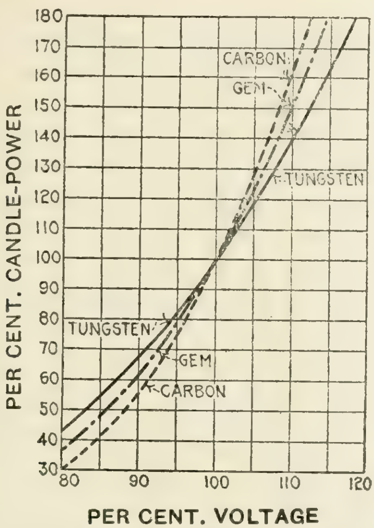


Fig. 7.—Curves showing variation in candle-power due to voltage variation, for carbon, gem and tungsten lamps.

per year; and who can state the advertising value? The ultimate saving will eventually warrant the rewiring of old cars to enable the use of tungsten lamps and reflectors. Where new cars are under construction the installation cost to the builder will be lower with the tungsten lamp and reflector system.

In order to check up the estimated advantages of the use of tungsten lamps in street railway service, a considerable number of both illumination and service tests have been conducted. As a result of these tests several railway companies, both large and small have standardized the tungsten lamp and re-

flector center deck system of car lighting, are having it installed in all new cars and are rewiring some of the old ones.

TESTS.

It may be of value to give a brief summary of tests conducted on typical types of cars and typical lighting equipment. In Table I tests *A* and *B* were made on ordinary small cars, *A* being lighted by the not uncommon systems of grouping 64-watt carbon lamps on the center deck. In car *A* there were four lamps in the center of the car, two lamps located four feet to each side of the center and one at each end. This resulted in very uneven illumination, there being a maximum of 9.75 foot-candles in the center of the car, which fell to 1.5 at the ends. Car *B* was a similar car, lighted with five 56-watt tungsten lamps and clear prismatic reflectors in the car body. The illumination in this car was very uniform, having a value of 6.5 foot-candles in the center and 2.25 at the extreme ends. This was obtained with a considerable saving in energy and a large reduction in glare.

Cars *C* and *D* were typical 34-foot cars, *C* being lighted with fifteen 64-watt carbon lamps in the car body and car *D* with six 56-watt tungsten lamps equipped with clear prismatic reflectors. Comparison of these two cars shows that the average illumination in the car *D*, is considerably greater than that of the car with carbon lamps; that the effective lumens per watt vary by so great a difference as 0.4 to 2.4 in favor of the tungsten lamps; also that glare was practically eliminated in car *D*.

Car *E* is a typical twenty-eight foot car lighted with gem lamps grouped under flat steel porcelain enamel reflectors, while car *F* is a similar car lighted with two rows of 36-watt tungsten lamps equipped with clear prismatic reflectors on the center deck. In this car transparent signs are used, which depend entirely on the interior light of the car, for their illumination. It will be seen that this car has a considerably higher average intensity which, due to the absence of glare, gives an effective illumination even higher than the intensity values indicate, as no photometer will measure the effect of glare.

Car *G* is a 34-foot car similar to car *B*, but in which the carbon lamps have been replaced by one circuit of 94-watt

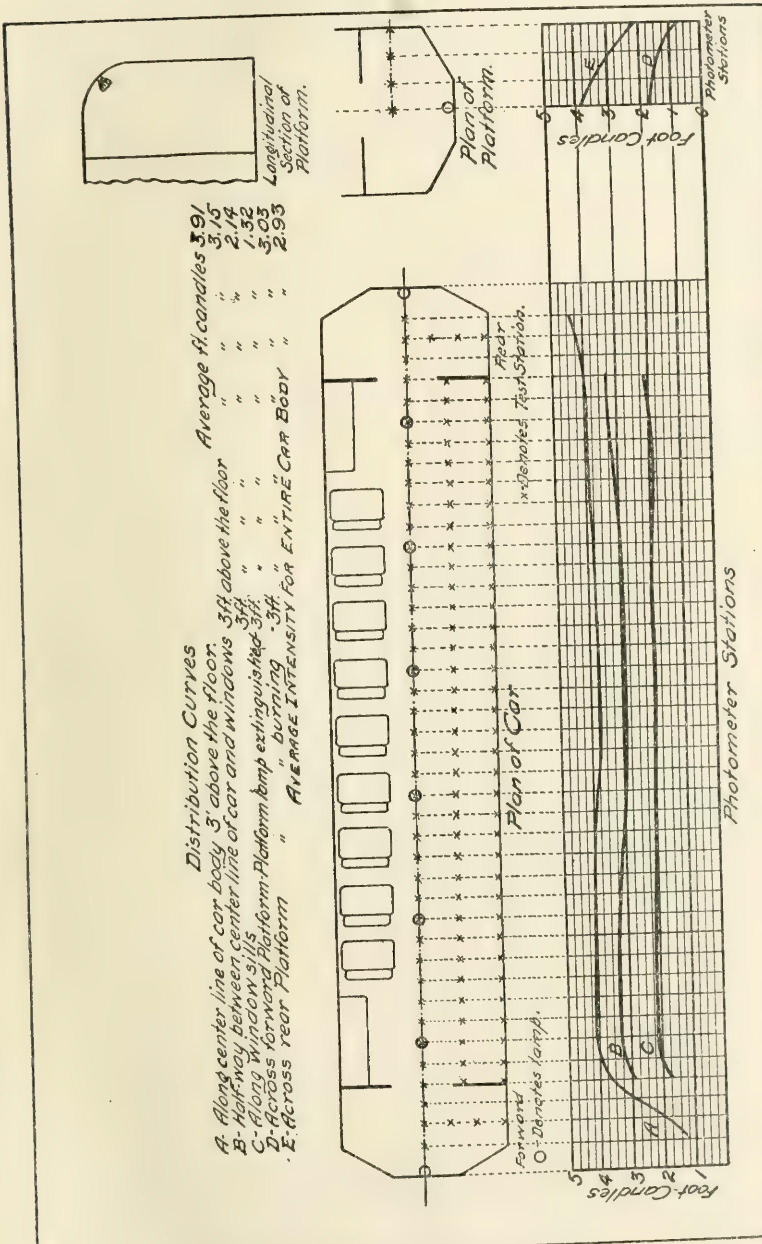


Fig. 8.—Diagram of a 34-ft. railway car equipped with 56-watt tungsten lamps and prismatic reflectors.

TABLE I.

Railway company	Size of car body	Interior finish of car body	Lamps used in car body	Average foot-candles on 3-ft. horizontal plane	Lumens per sq. ft. in car body	Effective lumens per watt in car body	Total watts on car for lighting, body, platform and signs	Cost of illumination† at car at 1c. per kw-hr
Mass. & Northern St. Rwy. Co., Athol, Mass.	*A* 8′ x 24′	Light mahogany and bird's eye maple headlining	10 64-watt carbon	4.0	8.58	1.3	960	$0.01135
	B 8′ x 24′	Dark green	5 56-watt tungsten with clear prismatic reflector	4.0	11.48	2.9	560	0.00935
Bay State St. Ry. Co., Boston, Mass.	*C* 8′ x 34′	Dark yellow	15 64-watt carbon	1.5	9.15	0.4	1,600	0.01892
	D 8′ x 34′	Dark yellow	6 56-watt tungsten with clear prismatic reflector	2.9	10.25	2.4	560	0.00935
Capitol Trac. Co., Washington, D. C.	*E* 8′ x 28′	Mahogany olive; green headlining	11 54-watt gem with flat steel porcelain enamel reflector	3.2	9.2	1.2	810	0.01060
	F 8′ x 28′	Mahogany olive; green headlining	8 36-watt tungsten with clear prismatic reflector	5.2	9.5	4.0	360	0.00652
Cleveland Rwys., Cleveland, Ohio	*G* 8′ x 34′*	Dark yellow	4 94-watt with alba reflector	37″ plane 4.2	11.3	3.4	585	0.01064
Bklyn. Rapid Tr. Co., Brooklyn, N. Y.	*H* 8′ x 28′	Dark yellow	14 23-watt tungsten	2.2	10.6	1.53	460	0.01043
	I 8′ x 42′	Red; white headlining	15 23-watt tungsten	42″ plane 2.7	7.6	2.6	460	0.01043

* Data furnished by Macbeth-Evans Glass Co., Pittsburgh, Pa.

Lumens per watt:

64-watt carbon	2.6
23-watt tungsten	7.4
36-watt tungsten	7.4
56-watt tungsten	8.17
94-watt tungsten	8.17
54-watt gem	3.46

†List prices of lamps:

64-watt carbon	14c.
23-watt tungsten	35c.
36-watt tungsten	35c.
56 watt tungsten	45c.
94-watt tungsten	80c.
54-watt gem	20c.

tungsten lamps equipped with alba reflectors, four being located in the car body and one on each platform. In addition to these there is one circuit of 23-watt lamps for signs and headlight. The distribution curves show that the illumination in this car, while of excellent intensity and quality, is not quite so uniform as was obtained with the 56-watt system in car *D*. This is due to the necessarily long spacing, where but four lamps are used in a thirty-four foot body.

Car *H* is a typical twenty-eight foot car in which the old carbon lamps have been replaced, lamp for lamp, by 23-watt clear bare tungsten lamps.

Car *I* shows well the enormous advantage of white headlining. In this car, though lighted with semi-indirect fixtures the average illumination with but 23 watts higher energy consumption is equal to that of car *H* (readings taken on a 42-inch plane are accordingly higher than on a 36-inch plane). This is due to the dark yellow ceiling of car *H* and the white porcelain enamel of car *I*. After these two cars have been in service for some time the depreciation in car *I* will undoubtedly be considerable higher than in car *H*.

It may be apropos, where so much stress has been laid on the question of glare, to call attention to the fact that the more light thrown directly in the eyes of an entering passenger the more brightly illuminated will the car appear. To an outside observer or an entering passenger, at first glance the car lighted with properly diffused light will appear darker than one lighted with clear, bare lamps, though the former may actually deliver far more light on the reading plane, where it is of service. A few moments' reading in such a car makes its comfort over the glary one very apparent.

METHODS OF TEST.

In making photometer tests in street cars readings are generally taken on a horizontal plane 36 inches above the floor. The width of the car is divided into 5 parts and a line of stations run through the center of each division; thus in an eight foot car one line of stations would be directly down the center of the car, the next 19 inches towards the side of the car and the third 38 inches from the center line. Along these lines stations are

chosen over the forward edges of the cross seats. Their location gives the average positions in which passengers hold their reading matter. Where long seats are used the stations are generally taken every two feet lengthwise in the car. Due to the fluctuating voltage of a trolley circuit it is necessary to take voltage and photometric readings simultaneously. In order to make one test comparable with another, each photometer reading must be corrected for voltage to the normal voltage of the lamps used.

Usually five readings are taken at each photometer station. In some instances, particularly where relatively great spacing of the lighting units is in use, it is of value to take readings on 45-degree planes towards each end. The ratio of these readings multiplied by the horizontal values gives an arbitrary measure of the relative effectiveness of the lighting system.

In order to obtain figures on the cost of operation of different systems which may be applied to any road the authors submit Table II, figured on the assumption that energy delivered at the car costs 1 cent per kilowatt hour and that lamps are purchased on a $1,200 contract and have a service life of 1,200 hours. The resultant figure shows the cost of lamp renewals plus the cost of energy per lamp per hour. By multiplying the resultant figure thus obtained, *i. e.*, cost per lamp per hour by the number of lamps per car by the number of cars in service by the total car hours of illumination per year, a figure showing the cost of illumination per year is easily obtainable. In figuring the car hours of illumination, account should be taken of the percentage of total cars in service which operate all night and those which operate three fourths, one half or one fourth of the night, etc. The lighting hours vary throughout the year, but an average of ten hours per night is a conservative figure covering all night burning the entire year round.

TABLE II.

Lamps	Cost of renewals per hr. (1,200 hrs. life). $1,200 basis	Cost of power per hr. at 1c. per kw-hr.	Total operating cost, *i. e.*, renewals and energy per lamp per hr.
64-watt carbon.....	$0.0008	$0.00064	$0.00072
23-watt tungsten...	0.00021	0.00023	0.00044
36-watt tungsten...	0.00021	0.00036	0.00057
56-watt tungsten...	0.00027	0.00056	0.00083
94-watt tungsten...	0.00048	0.00094	0.00142

No figures have been given for the cost of cleaning and maintenance of reflectors, where reflectors are used, as the authors were unable to find any accurate data on this subject.

SUMMARY.

The use of tungsten lamps in place of carbon is highly advantageous because they produce better illumination at an actual saving in operating expense. Where tungsten lamps are used it is highly desirable to install efficient reflecting devices to reduce glare and increase the efficiency of light utilization. In all cases a light interior car finish is to be desired.

DISCUSSION.

Mr. J. R. Cravath: Until very recently there has been a scarcity of reflectors and reflector holders suitable for use on electric railway cars. There are now substantial holders on the market, but suitable reflectors are few. Glass manufacturers have been slow to offer simple designs which would involve small cleaning cost because such simple designs would not be sufficiently distinctive to permit of design patents.

On account of having been in the railway business myself in the past, I probably appreciate more than some others, the importance of having reflectors which are easily cleaned. Most of the reflectors offered up to date have, in my opinion, too many creases and crevices in which dirt can lodge where it is not easily unlodged by the car cleaner. If electric railway companies will have their own reflector designs made, and order in large quantities, they can be made up cheaply by any reflector manufacturer.

This paper brings up the fact that there is a difference in efficiency of about two to one between bare lamps and lamps with proper reflectors. This is confirmed also by the extensive and careful series of tests on steam railway day coach lighting conducted this year at Cleveland, under the auspices of the Illumination Committee of the Association of Railway Electrical Engineers. These results are summarized briefly in the accompanying table in which the different forms of reflectors and enclosing units are classified and the average illumination obtained above

the seats upon reading pages, held at an angle of 45°, is given for each class.

When both expense of proper cleaning and efficiency is considered I think a very simple design of heavy density opal reflector is the best for electric railway service.

1913 TESTS, ELECTRIC LIGHTING, RAILWAY DAY COACH.

Comparison of Various Types of Lighting Units from Point of View of Illumination Efficiency. All results reduced to same total wattage representing 66⅔ generated lumens per running foot of car.

Type of unit	Average illumination on 45 deg. reading planes at seats. Foot-candles.
Open mouth reflectors—	
Mirrored glass reflectors	2.79
Prismatic clear reflectors	2.42
Heavy density opal reflectors	2.14
Enclosing unit—	
Prismatic reflectors (deep bowl type) and bowl	1.89
Open mouth reflectors—	
Medium density opal reflectors	1.83
Prismatic satin finish reflectors	1.72
Light density opal reflectors	1.66
	1.40
Semi-indirect units—	
Diffusing shades (standard pullman opal shade)	1.35
Enclosing units—	
Reflecting and diffusing globes (satin finish corona)	1.34
Reflecting and diffusing type of units	1.32
Prismatic reflector (shallow bowl type) and bowl	1.24
Totally indirect units	1.23
Bare lamp	1.15
Enclosed unit, light density opal globe	1.03

MR. J. L. MINICK (Communicated): This paper should be of considerable value to engineers interested in car lighting, not only those connected with street railway companies, but those connected with steam roads. I am a little disappointed, however, that the paper does not go back far enough into past history. Those who have to do with the design of new and the remodeling of old equipments, and the operation of them, find it necessary continually to refer to what has been done in the past. And most of what has been written on the subject of car lighting gives very little engineering information. Consequently it is of comparatively little value.

Aside from the question of lighting, this paper calls attention in an indirect way to the necessity of someone designing a regulator which will permit the operation of lamps in multiple instead of in series. Such a regulator should be so designed as to take care of all the fluctuations in voltage and maintain an absolute and fixed voltage across the lamps themselves. There is a crying need for a device of this kind, and if one can be worked out successfully, it will undoubtedly be in great demand.

Mr. S. G. Hibben (Communicated): If, as in the cars that are equipped with a carbon lamp lighting system, it is found that the illumination is inadequate, then merely replacing the carbon lamps by the bare 23-watt tungstens in the same receptacles will not increase the useful illumination by any appreciable amount. It will still be inadequate. The authors save found an increase of 6 per cent.; in another case this has been measured as 10 per cent., and the theoretical increase (of horizontal candle-power) is from 16 c-p. to 17.16 c-p. or 7.3 per cent. When used in a pendant position, the inherent distribution characterists of the unshaded tungsten lamps are slightly poorer than the carbon characteristics for downward lighting.

The fact should not be overlooked, that the prime object of indirect lighting as mentioned on the eighth and ninth pages is to reduce glare. In this kind of service the indirect system at the present time does not appear to be practical or advisable, for in street cars the ceiling or secondary reflecting surface is very little higher above the floor than the primary light sources, and if there is to be any attempt at economy, this ceiling surface must be almost white, and easily cleaned so as to be kept so. This means that the ceiling should have a gloss and not a matt surface, and it follows that the glare from a low white glossy ceiling will be nearly as bad as that from the glass reflectors themselves.

As regards the reflectors used in street cars, the authors have mentioned the advisability of an intensive type, which is apparent when noting that the average width of cars is 8 feet, and that the large units are spaced about this same distance. The average height above the floor is also about 8 feet, so that the maximum light from reflectors should be in the neighborhood of the 30° to 40° angle. The reflectors should be deeper than the ones used

in buildings, for the same size of lamp bulbs, chiefly because the lighting units are often in the field of vision and, secondly, it is not advisable to use bowl frosted lamps.

The first cost of the installation in a street car, mentioned on the twelfth and thirteenth pages, is a figure that varies with the different companies. Roughly, it should be about as follows:

A. The installation of 5 94-watt tungstens in one car.

*5	Holders complete	$6.25
*5	94-watt shades	3.00
1	Selector switch	4.00
150	Ft. No. 14 d. brd. wire	1.50
	Small incidentals	1.50
	Total (not including labor)	$16.25

B. The installation of 25 60-watt carbons in one car.

25	Receptacles	$6.25
125	Ft. wire	1.25
	Small incidentals	1.75
	Total (not including labor)	$9.25

The difference is $7.00. If the saving in energy by using the tungsten lamps results in a saving of from 1 to 1.5 cents per car per hour of lighting, it would take about 470 to 700 hours to pay for the excess cost of the new equipment. This is equivalent to from 1 to 2 months time of service.

* The sixth or auxiliary unit may or may not be equipped with a reflector. In some cases it is recessed into the ceiling.

THE LIGHTING OF A SIMPLE HOME.*

BY A. L. POWELL.

Synopsis:—This paper describes, in detail, room by room, interesting changes made in the lighting of a private home. The original installation was inartistic as well as inefficient; the essential features of the remodelled one are eye-protection, artistic appearance and diffusion. Results of illumination tests and night photographs made before and after the changes were made are presented. Data from photometric tests of the lamps and reflectors originally found in the house are also given. The author makes a brief plea for better illumination in homes and residences.

Residence lighting is a problem with many variables. No specific rules may be laid down for its solution, for individual tastes vary widely. The home, with regard to its lighting, is in a class with the church, theatre and hotel, in that the decorative elements predominate; yet its lighting is of course different, for these buildings must cater to the demands of the community as a whole; whereas the home fulfills the requirements of an individual or of a small group. It is a logical conclusion, therefore, that there must be considerable variation in what might be termed good residence lighting. The ideas of an individual, in most cases the owner, must be more closely adhered to than in any other class of lighting.

A survey of the existing installations, in apartment houses and in the average private home, shows there is much work to be done along lines of improvement.

If a person had a piece of furniture in his house which was ugly and old fashioned, yet not an antique, it would soon be disposed of; if he had a furnace which required much coal to produce a little heat, it would be replaced by a more efficient one; if there were an opening in the wall which emitted a draft of air, making the room uncomfortable and likely to affect the health of the occupant, it would be repaired. With regard to the lighting, however, similar deficiencies are apparently un-

* A paper to be read at a meeting of the New York Section of the Illuminating Engineering Society, January 8, 1914.

noticed, for there is an abundance of antiquated types of fixtures and inefficient lamps; eye protection is not assured because most of the glassware possesses but little diffusing power.

A few years ago there were not many lighting auxiliaries on the market from which to make a selection, but now standard material is available in such variety that glassware, lamps and fixtures can be secured to harmonize with any predetermined scheme of decoration. An excellent feature of most of these devices is that they are not only designed along artistic lines, but they produce good diffusion and are relatively efficient. This last factor, however, should be given but little consideration in lighting the home, for the artistic effect of the completed installation is the great essential; and used in its broadest sense the word artistic implies a thoroughly comfortable condition.

This paper is not intended as an outline of the general subject of residence lighting, but is rather a description of one particular installation. The lighting requirements briefly outlined for the various rooms may differ slightly from those of corresponding rooms in other homes. There is one point, however, which the author believes warrants presentation; that is, nothing experimental has been used; all the equipment is stock material; and the ideas here set forth may suggest to the layman others which he can apply directly.

About six months ago, the writer moved into an apartment which was electrically lighted, but the fixtures, glassware and lamps were of a kind which left much to be desired. The lighting throughout has been changed and these changes are here outlined. They show how simple a matter it is to improve conditions. While the installation at present may not be perfect in many respects, most of the observers who have seen it have said that it is a marked advance over the old installation which may be considered typical of a large number of others.

Voltage Check.—As a preliminary step, using both recording and indicating volt meters, careful tests were made to determine the average voltage at which the lamps would operate when in normal service. The voltage is higher during the day than during the hours of peak load, so approximately 50 readings were taken on various days between the hours of 5:30 and 10:30

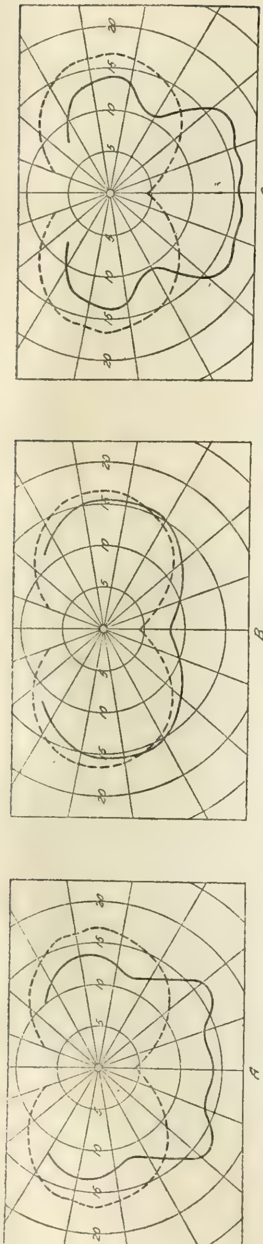


Fig. 2.—Vertical distribution curves of a 16.8 candle-power, 50-watt carbon lamp equipped with glassware shown in Fig. 1.

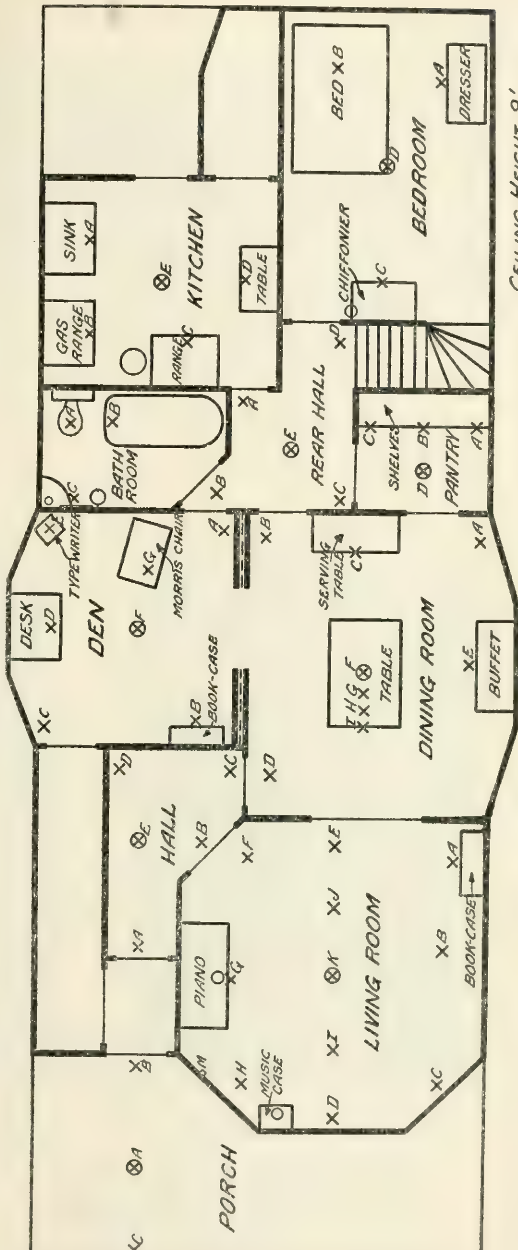


Fig. 3.—Floor plan showing location of outlets and test stations.

P. M. The average of these was taken as the normal operating voltage.

Lamps.—The house was equipped with an assortment of carbon and metalized carbon lamps of various voltages. These lamps were removed and photometered at the voltage found from the test; namely, 112. The efficiency of the lamps was very low, for two reasons: first, many of the lamps were of a higher voltage than the circuit; second, several were somewhat blackened by carbon deposit. From the 16 lamps the following results were obtained:

	Volts	Candle-power	Watts	Watts per candle
Maximum efficiency	112	16.6	49.0	2.95
Minimum efficiency	112	10.3	48.7	4.75
Average efficiency	112	13.3	52.0	3.9

Glassware.—But three varieties of reflecting and diffusing media were used in the first installation. These are shown in Fig. 1, and the vertical distribution of light obtained from each one of them, using a 50-watt, 16.8 candle-power carbon lamp, is shown in Fig. 2.

(A) SQUARE ROUGHED INSIDE CRYSTAL GLASS SHADE.

	Per cent.
Total lumens clear bare lamp	100
Total lumens lamp and reflector	86
Downward lumens lamp and reflector	51
Lumens in 0 to 60° zone lamp and reflector	28

(B) ROUGHED INSIDE CRYSTAL BALL.

	Per cent.
Total lumens clear bare lamp	100
Total lumens lamp and globe	90
Downward lumens lamp and globe	48
Lumens in 0 to 60° zone lamp and globe	24

(C) IMITATION PRISMATIC CRYSTAL GLASS SHADE.

	Per cent.
Total lumens clear bare lamp	100
Total lumens lamp and reflector	80
Downward lumens lamp and reflector	47
Lumens in 0 to 60° zone lamp and reflector	27

Fig. 1.—Types of glassware used in connection with the original installation.

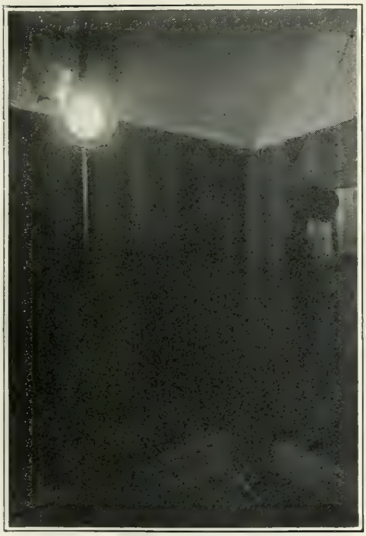


Fig. 4.—Night photograph showing the illumination of the front hall (old equipment).

Fig. 5.—Night photograph showing the illumination of the front hall (new equipment).

Fig. 6.—Night photograph showing the illumination of the living room (old equipment).

Fig. 7.—Night photograph showing the illumination of the living room (new equipment).

Location of Outlets.—In general, the location of the outlets was satisfactory, although if the writer had designed the installation, a few changes would have been made, more for the sake of convenience of control rather than from an illumination standpoint. Fig. 3 shows the arrangement of rooms on the first floor and the locations of outlets.

Tests.—Before changing the equipment, illumination tests were made of the installation as found, using a calibrated Sharp-Millar portable photometer in the regular manner; testing lamps were then installed and afterwards photometered at the test voltage. The test values were corrected to standard. Photographs were taken at night of all rooms, before and after the changes. It is realized that the photographic method, as ordinarily applied, does not accurately indicate the effectiveness of the illumination, but is of value in showing, at a glance, the relative intensities in various parts of the room. The illustrations are particularly useful in showing the types of equipments. The illumination test values show the quantitative element.

FRONT HALL.

This is a small room 10 ft. by 4 ft. 6 in. (1.37 m.), 45 sq. ft. (4.18 sq. m.) which serves merely as an entrance and a place to leave wraps; hence very little light is needed. The ceiling is white and the walls are dark green, making the effective illumination relatively low. Fig. 4 shows the old equipment—a combination gas and electric fixture with an imitation prismatic shade and a globe as shown by "B," Fig. 1. The lamp is 7 ft. (2.13 m.) above the floor. The 50-watt clear carbon lamp was replaced by a 10-watt clear tungsten filament lamp. The clear glass gas shade was replaced by a pressed opalescent glass reflector, (merely for appearance as this is not used) and the enclosing ball by an acorn shaped, opalescent enclosing unit, (1) roughed outside (shown in Fig. 5). The intensity of illumination from the electric lamp is sufficient for this particular hall, (the average hall would require more illumination,) and the diffusion is much improved. The light is controlled by a key socket, although it would be preferable to have a wall switch.

Illumination Readings.—The stations are shown in Fig. 3. All readings were taken on a 3 ft. (0.91 m.) horizontal plane.

Stations	Actual illumination old equipment	Illumination old equipment corrected to 50-w., 2.97 w. p. c. carbon	New equipment tungsten filament at 1.40 w. p. c.
A	0.29	0.34	0.10
B	0.57	0.68	0.19
C	0.39	0.46	0.13
D	0.37	0.43	0.14
E	0.86	1.02	0.36

LIVING ROOM.

The living room is 13 ft. x 14 ft.—170 sq. ft.—(3.96 m. x 4.27 m.—15.79 sq. m.). Fig. 6 shows the old fixture equipment to be a 4-arm combination gas and electric chandelier of square metal tubing, with four 50-watt clear carbon lamps and shades, (shown by "A," Fig. 1); the lamps are 6 ft. 8 in. (2.03 m.) from the floor, and are controlled by a wall switch. This unit, while not really objectionable, was not particularly artistic; diffusion was not as good as desirable, and there was a tendency for the light to be strongly concentrated beneath the fixture.

Comfort is especially desirable in a room of this nature where a social hour is to be spent, and with the white ceiling and dark green walls a semi-indirect system of illumination is quite applicable. The dark walls remove the impression of an extremely bright room occasionally experienced with this system with very light surroundings. The fixture was replaced by a pressed opalescent bowl (2) roughed outside and antique finish; brass chains suspend the bowl and a 60-watt clear tungsten filament lamp about 7 ft. 6 in. (2.28 m.) from the floor.

A baseboard receptacle was installed at the point marked "M," to supply an iridescent glass portable lamp (3) located on the music stand. In the body of this lamp is a 15-watt clear round bulb candelabra type tungsten filament lamp; in the base there is a 15-watt clear tubular bulb candelabra type tungsten filament lamp. On the piano is located a brass portable lamp, (4) with a matt aluminum interior reflecting surface and a tubular 25-watt tungsten filament lamp. The appearance of the installation is shown in Fig. 7.

Illumination Readings.—The stations as shown in Fig. 3.

Stations		Actual illumination old equipment	Illumination old equipment correct to 4-50 w., 2.97 w. p. c. carbon	New equipment tungsten-filament at 1.12 and 1 17 w. p. c. Center light only	All lamps burning
A	3 ft. (0.91 m.) horizontal plane	0.62	0.52	0.50	—
A	Vertical at top bookcase	0.77	0.65	0.59	—
A	Vertical at bottom bookcase	0.56	0.47	0.52	—
B	3 ft. (0.91 m.) horizontal plane	1.10	0.93	1.00	—
C	3 ft. (0.91 m.) horizontal plane	0.97	0.81	0.69	—
D	3 ft. (0.91 m.) horizontal plane	1.30	1.10	0.90	0.98
E	3 ft. (0.91 m.) horizontal plane	0.71	0.59	0.57	—
F	3 ft. (0.91 m.) horizontal plane	0.80	0.67	0.58	—
G	3 ft. (0.91 m.) horizontal plane	1.85	1.55	1.23	7.10
G	Vertical at center of piano............	1.80	1.50	1.19	8.6
G	Vertical 1 ft. from center	—	—	—	4.15
H	3 ft. (0.91 m.) horizontal plane	0.96	0.81	0.83	1.36
I	3 ft. (0.91 m.) horizontal plane	2.60	2.20	2.04	2.08
J	3 ft. (0.91 m.) horizontal plane	2.60	2.20	1.75	—
K	3 ft. (0.91 m.) horizontal plane	6.60	5.50	3.43	3.45

DINING ROOM.

Practise varies widely in the lighting of this room of the house. Many persons prefer a low general illumination from a shower fixture or other type of ceiling source, with localized illumination provided by candles on the table; others, including the writer, favor the art glass dome over the center of the table, and this type of equipment was present in the house when taken. An amber art glass hemispherical dome was hung so that the lamp or the center of the dome was 4 feet 9 inches above the floor and equipped with 2 50-watt clear carbon lamps in sockets at angles, controlled by a wall switch. As it was desired to use various electric cooking utensils, and no baseboard or floor receptacle was available, one of the sockets in the dome

is utilized for this purpose, as shown in Fig. 8. The attachment cord is passed through an opening in the top of the dome, and when not in use it is coiled about the supporting rod and hidden from sight by the decorations at the top. A 45° socket was substituted for the second socket. A clear 60-watt tungsten filament lamp with a clear prismatic reflector (5) furnishes the illumination. The entire base of the dome is covered by a screen of light yellow messaline, held in place by a flexible wire ring. This diffuses the light excellently, the character of the illumination is mellow and no light source is visible. These advantages compensate for the rather high absorption of the screen, and the reflector has so much better redirecting properties than the glass of the fixture that almost

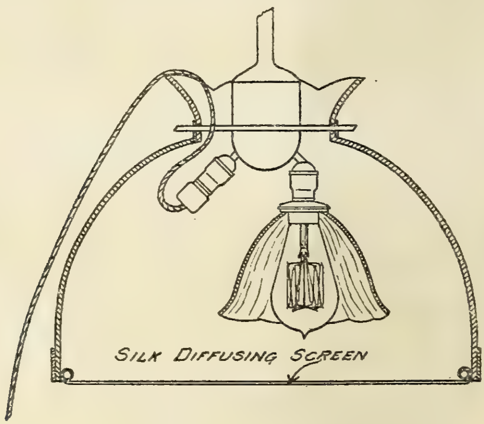


Fig. 8.—Arrangement of accessories in dining room dome.

as much light is effective as with a clear lamp without a reflector or screen. The arrangement is exceptionally satisfactory when doilies are used on the polished table top, as it precludes all glaring reflection.

An art glass window in the wall above the buffet is illuminated from without by 3 15-watt clear tungsten filament lamps in a mirrored trough reflector (6). When the window is lighted, the room has the effect of receiving a flood of sunlight, for the glass is of a warm hue and the reflector so constructed as to give a relatively strong directional effect. The intensity on a 3-ft. (0.91 m.) horizontal plane, with the room illuminated by

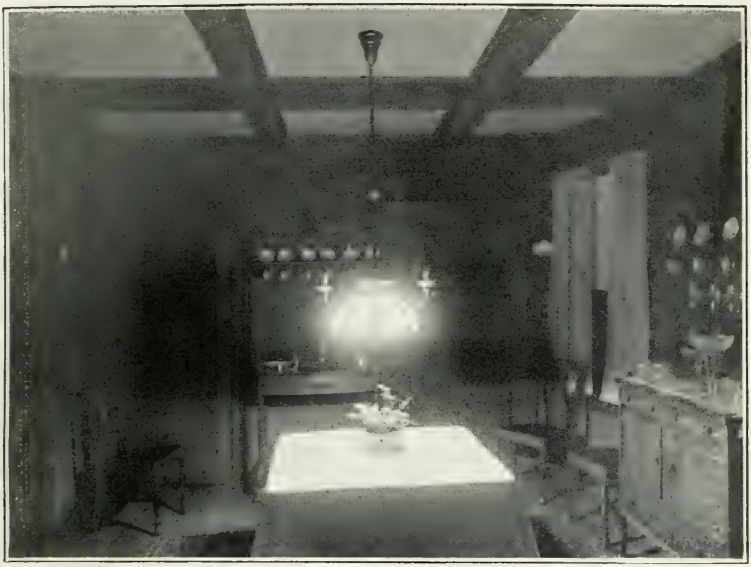


Fig. 9.—Night photograph showing the illumination of the dining room (old equipment).

Fig. 10.—Night photograph showing the illumination of the dining room (new equipment)

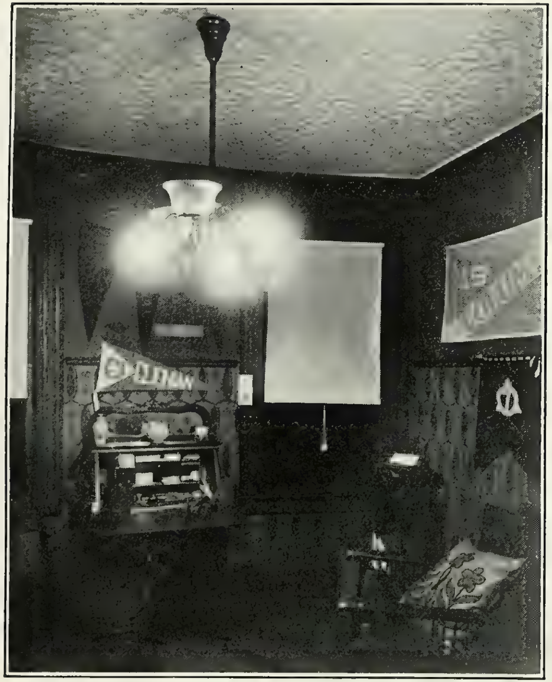


Fig. 11.—Night photograph showing the illumination of the den (old equipment).

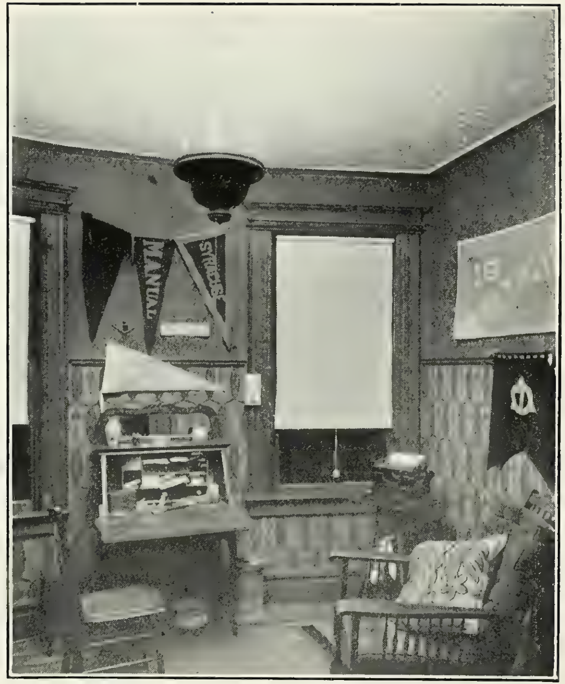


Fig. 12.—Night photograph showing the illumination of the den (new equipment).

the window, is very low near the wall and rises to a maximum about 4 ft. (1.21 m.) out and then gradually decreases.

It is true that the illuminating efficiency of the lighting system is very low, but this is to be expected, for not only are the lighting units dense, but the wall is covered with a brown burlap wainscoting with dark green and brown figured paper above; the woodwork and ceiling panelling are of dark chestnut.

Figs. 9 and 10 show the effect before and after the changes.

Illumination Readings.—The test stations are shown in Fig. 3. The first five readings indicate the illumination on a 3 ft. (0.91 m.) horizontal plane; the others, the illumination at stations 1 ft. (0.30 m.) apart at the table level.

Stations	Actual illumination old equipment	Illumination old equipment corrected to 2 50-watt, 2.97 w. p. c. carbon lamps	New equipment tungsten filament lamps at 1.12 w. p. c. and 1.3 w. p. c.
A	0.05	0.05	0.14
B	0.05	0.05	0.20
C	0.14	0.15	0.61
D	0.06	0.07	0.24
E	0.45	0.50	1.3
F	12.50	13.70	11.4
G	6.20	6.80	7.7
H	2.50	2.70	2.63
I	1.10	1.20	1.05

DEN.

This is a relatively small room 11 ft. x 10 ft. 110 sq. ft.—(3.35 m. x 3.05 m.—10.22 sq. m.) used for reading, playing cards, writing, etc. Fig. 11 shows the old lighting equipment a combination gas and electric multi-arm chandlier, which was inadequate, as well as unattractive. Three 50-watt clear carbon lamps with shades, as shown by "C," Fig. 1, were in use; the lamps were installed at angles of 45° with the vertical and but 6 ft. 6 in. (1.98 m.) above the floor and were controlled by key sockets. The glare was extreme; there was practically no diffusion, and the distribution was very unsatisfactory, a condition which was particularly noticeable when one played cards on the table located in the center of the room. The direction of light was such as to place the faces of the cards into shadow.

The fixture was replaced by a totally indirect unit (see Fig.

12) consisting of a one-piece mirrored glass reflector in a casing (7) of an Egyptian design which has a sand blasted finish and brushed brass high lights. The chain suspension is of such length as to bring the lamp 7 ft. 3 in. (2.21 m.) from the floor. A 100-watt clear tungsten filament lamp is used, controlled by a pull switch in the base of the fixture.

Although the ceiling is white, the walls are of dark green paper with a brown wainscoting, which causes the illumination efficiency to be relatively low. The distribution is good and the general effect pleasing. The intensity is sufficient for the conditions to be met, yet it is not high enough for fine work, such as sketching, etc., and it is planned to install a baseboard receptacle near the desk and use a suitable local lamp at the desk when required. A suitable intensity could be secured with a larger lamp in the center outlet, but from the standpoint of economy the first scheme seems desirable.

Illumination Readings.—The stations are shown in Fig. 3.

Stations		Actual illumination old equipment	Illumination old equipment corrected to 3 50-w. 2.97 w. p. c. carbon lamps	New equipment tungsten filament lamps at 1.08 w. p. c.
A	3 ft. (0.91 m.) horizontal...	0.60	0.69	0.96
	45° toward light	0.96	1.09	1.42
B	3 ft. (0.91 m.) horizontal...	0.51	0.58	1.28
	Vertical top bookcase	0.81	0.92	0.94
B	Vertical bottom bookcase...	0.25	0.29	0.30
C	3 ft. (0.91 m.) horizontal...	0.40	0.46	1.09
D	Horizontal desk level	1.42	1.62	1.73
D	Horizontal desk level shadow test-writer in position	0.73	0.83	1.69
E	Horizontal typewriter level.	0.56	0.64	1.19
	45° toward light	1.07	1.22	1.56
F	3 ft. (0.91 m.) horizontal...	4.10	4.70	2.30
G	45° plane away from light position of paper in reading	0.91	1.04	0.87

PANTRY.

The old equipment of a straight pipe combination gas and electric fixture with a shade, as shown by "C," Fig. 1, and a 50-watt clear carbon lamp at an angle of 45° with the vertical, 6 ft. (1.83 m.) from the floor, gave a poor distribution of light. It is desirable to have the maximum illumination at the top shelf where there is greatest danger of breakage.

The fixture was replaced by a canopy and nipple, with an in-

Fig. 13.—Night photograph showing the illumination of the pantry (old equipment).

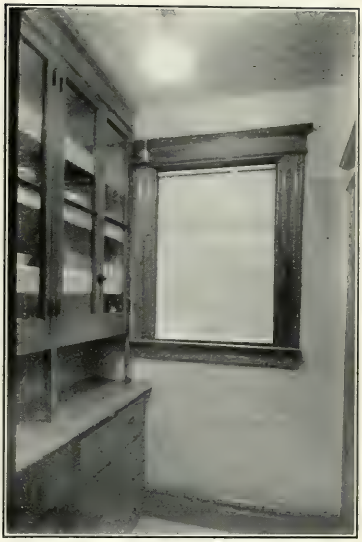


Fig. 14.—Night photograph showing the illumination of the pantry (new equipment).

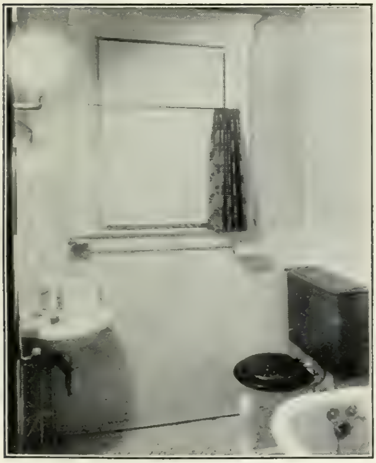


Fig. 15.—Night photograph showing the illumination of the bath room (old equipment).

Fig. 16.—Night photograph showing the illumination of the bath room (new equipment).

Fig. 17.—Night photograph showing the illumination of the bed room (old equipment).

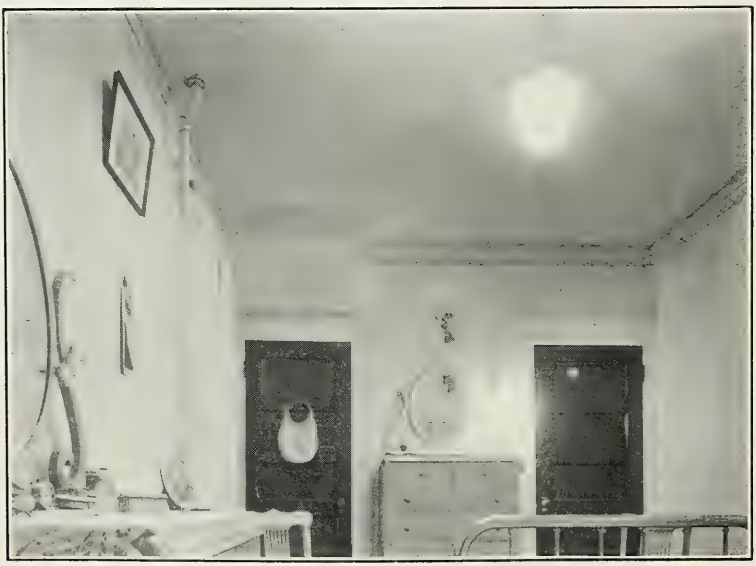


Fig. 18.—Night photograph showing the illumination of the bed room (new equipment).

direct shade holder (8) holding a cased opalescent bowl-shaped glass reflector. (9) A 15-watt clear tungsten filament lamp supplies ample illumination, well distributed over all of the shelves. Control is by means of a pendant switch. The white ceiling and light buff walls serve as efficient diffusers. Figs. 13 and 14 show the appearance before and after the change.

Illumination Readings.—The test stations are shown in Fig. 3.

Stations	Actual illumination old equipment	Illumination old equipment corrected to 1 50-watt, 2.97 w. p. c. carbon lamp	New equipment tungsten filament lamp 1.30 w. p. c.
3 ft. (0.91) horizontal plane.			
A	0.88	1.17	0.43
B	1.09	1.45	0.59
C	0.50	0.66	0.45
D	1.39	1.85	0.65
Vertical base of shelves.			
A	1.08	1.44	0.19
B	1.59	2.11	0.26
C	0.31	0.41	0.24
Vertical top of shelves.			
A	0.70	0.93	0.80
B	1.18	1.57	4.3
C	0.25	0.33	1.05

REAR HALL.

This serves merely as a passageway. While the original lighting, combination straight pipe gas and electric fixture with the type of shade shown by "C," Fig. 1, and a 50-watt clear carbon lamp, was adequate, it did not present a good appearance. The fixture was replaced by a short pipe fixture, 15-watt bowl-frosted tungsten filament with etched opal cylindrical shaped shade (10); the lamp is 7 ft. 6 in. (2.28 m.) above the floor and controlled by a pull socket. See Fig. 21.

Illumination Readings.—Stations as indicated in Fig. 3. All readings on a 3-foot horizontal plane.

Stations	Actual illumination old equipment	Illumination old equipment corrected to 50 w. 2.97 w. p. c. carbon	New equipment tungsten filament lamp at 1.30 w. p. c.
A	0.57	0.73	0.32
B	0.23	0.27	0.17
C	0.38	0.49	0.25
D	0.25	0.32	0.11
E	0.88	1.12	0.98

BATH ROOM.

As this is a small room (9 ft. x 6 ft.—2.74 m. x 1.83 m.) with walls, ceiling, floor and fittings of white, it is a simple matter to provide adequate illumination. The original equipment was a gas and electric combination bracket 5 ft. 6 in. (1.67 m.) from the floor, with a crystal shade (see Fig. 1 "C") and a 50-watt clear carbon lamp, as shown in Fig. 15. The objections to this equipment were as follows: first, when a person was shaving, the right side of his face was in a shadow, while the left side was well illuminated; second, the appearance was poor; and, third, with the bowl shaped shade at an angle of 45° the filament of the lamp was quite visible.

The fixture was replaced by a bracket in the form of an "L" with the key socket pointing upward, holding a 25-watt clear tungsten filament lamp and a bowl-shaped opalescent glass reflector (11). At the right side of the mirror was installed a cylindrical metal reflector (12) with a right-angle pull socket and a 25-watt all frosted tungsten filament lamp in a tubular bulb. This unit is used only while shaving. The diffusion and distribution are good; the direction and intensity of the light for shaving is excellent. Fig. 16 shows the improved appearance.

Illumination Readings.—The test stations are shown in Fig. 3.

Stations		Actual illumination old equipment	Illumination old equipment corrected to a 50-watt 2.97 w. p. c. carbon lamp	Illumination new equipment tungsten filament lamps at 1.17 w. p. c.
A	3 ft. (0.91 m.) horizontal plane	0.77	0.73	1.20
B	3 ft. (0.91 m.) horizontal plane	0.95	0.89	1.32
C	3 ft. (0.91 m.) horizontal plane	2.0	1.9	3.42
C	Shaving position toward wall	1.1	1.0	20.7
C	Shaving position away from wall....	6.0	5.6	3.5

BED ROOM.

The original equipment provided only one outlet, which was not adequate for a room of this size, 10 x 14 feet—140 sq. ft., (3.04 m. x 4.26 m.) The lighting unit which was neither decorative nor efficient, was a combination gas and electric wall bracket 5 ft. 6 in. (1.67 m.) from the floor, as shown near the chiffonier. The socket was pointed outward at an angle of 45° and a 50-watt clear carbon lamp was surrounded by a crystal shade like "C" of Fig. 1. The filament was entirely visible and there was practically no diffusion. (See Fig. 17.)

The illumination was strongly concentrated at one point; there was insufficient illumination for one to read in bed, and the illumination at the dresser was too low for fixing the hair and the like. These demands are seldom given sufficient attention in lighting the bedroom and yet they are very essential.

The room was very prettily finished: white ceiling, white and light blue wall paper, white woodwork and furniture decorations light blue. It was necessary to secure glassware which would harmonize with this; but there are many varieties of colored etched opalescent shades from which to make a choice. The wall bracket was fitted with a 45° socket, current tap, 15-watt round bulb clear tungsten filament lamp and a cylindrical-shaped diffusing shade. This was of cased glass having an etched design (13); the base portion is white, the background tinted grey and four light blue medallions with a white classic head in the center completes the design

A white silk-covered cord extends from the current tap, by way of the picture moulding, to the center of the ceiling; a three-chain ring-type fixture finished in verde supports a deep glass bowl (14), with a treatment similar to the diffusing shade, and a 40-watt clear tungsten filament lamp depending 7 ft. 8 in. (2.33 m.) from the floor. Both lights are controlled by the key socket. The distribution of light is even, as indicated by the figures and photograph No. 18, and the requirements mentioned are satisfactorily met.

Illumination Readings.—The stations as shown in Fig. 3.

Stations		Actual illumination old equipment	Illumination old equipment corrected to 50-w. 2.97 w. p. c. carbon lamps	New equipment tungsten filament at 1.3 and 1.17 w. p. c.
A	Illumination on vertical surface 5 ft. 6 in. (1.67 m.) from floor toward light...	0.19	0.28	1.31
A	Illumination on vertical surface 5 ft. 6 in. (1.67 m.) from floor away from light	0.07	0.08	0.29
A	Illumination horizontal surface 3 ft. (0.91 m.) from floor	0.12	0.14	1.53
B	Illumination on surface 45° from vertical, position of book of person reading in bed	0.11	0.13	0.91
C	Illumination vertical surface 5 ft. 6 in (1.67 m.) from floor toward light	3.16	3.70	4.40
C	Illumination on vertical surface 5 ft. 6 in. (1.67 m.) from floor away from light	0.25	0.29	0.61
C	Illumination top of chiffonier	1.40	1.80	2.86
D	Illumination horizontal surface 3 ft. (0.91 m.) from floor	0.48	0.56	2.16

BED ROOM (Second floor)

This room is of the shape and size of the room just described and was lighted in a similar manner. The arguments in favor of better illumination given above apply equally to this room. The changes are not completed at the time of writing, but these may be briefly outlined; on the bracket fixture it is planned to install a decorated etched glass diffusing shade, colored to harmonize with the room decorations. In place of the center outlet wires will be run to one unit placed at each side of the dresser. The equipment will consist of two portables with cast iron bases, heavy enough to prevent them being overturned when the pull socket is operated, and an upright of brushed brass pipe. Round-bulb, 15 or 25-watt tungsten filament lamps will be used with a wire framework covered with shirred silk matching the decorations, as shown in Fig. 22.

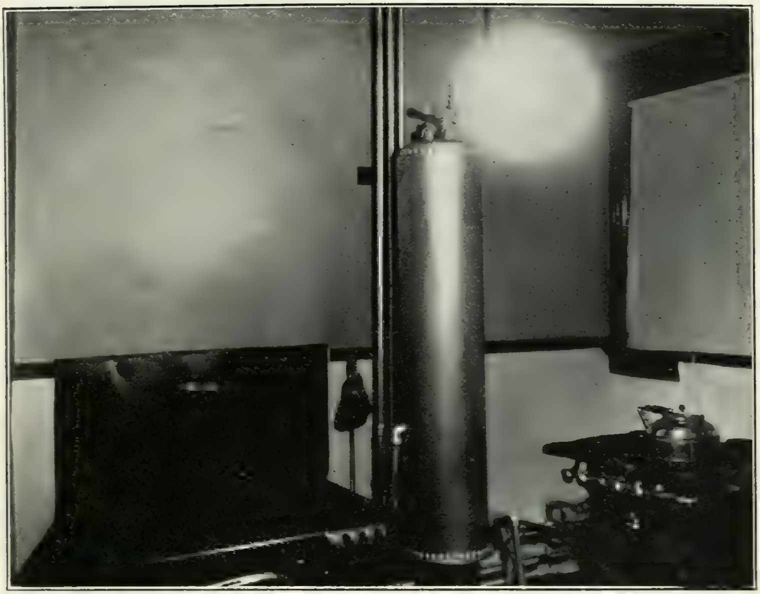


Fig. 19.—Night photograph showing the illumination of the kitchen (old equipment).

Fig. 20.—Night photograph showing the illumination of the kitchen (new equipment).

Fig. 21.—Night photograph showing the illumination of the rear hall (new equipment).

Fig. 22.—Night photograph of proposed method of illuminating dresser.

Fig. 23.—Night photograph showing the illumination of the cellar.

Fig. 24.—Night photograph showing the illumination of the porch (new equipment).

KITCHEN.

This is one of the few rooms in the house where evenly distributed illumination from properly placed lamps is of more importance than appearance. A relatively high intensity of illumination is necessary in order that the cooking may be done with facility. At least two units are usually required in even a small room such as the one shown in Fig. 19, which is but 9 x 11 ft. (2.74 m. x 3.35 m.) The table, sink and range must have good lighting, and if only one outlet is provided shadows will result.

The old equipment was a straight pipe combination gas and electric fixture, bringing the crystal shade, "C" of Fig. 1, and a 50-watt clear carbon lamp but 6 ft. 3 in. (1.90 m.) from the floor. Shadows were pronounced and the distribution was very unsatisfactory.

This fixture was replaced by a short pipe and chain hanger, a 40-watt clear tungsten filament lamp and an extensive prismatic reflector (15), hung 7 ft. 6 in (2.28 m.) from floor (see Fig. 20). For easy control, a ceiling switch was installed. The distribution of light is excellent, but it would have been desirable to have had two outlets, using proportionately smaller lamps.

The medium buff ceiling and walls prevent an economic use of an indirect system, which would undoubtedly remove the shadow objection cited above.

Illumination Readings.—The stations are shown in Fig. 3.

Stations	Actual illumination old equipment	Illumination old equipment corrected to a 50-watt 2.97 w. p. c. carbon lamp	New equipment tungsten filament lamp at 1.17 w. p. c.
A	0.56	0.49	1.02
B	0.57	0.50	1.11
C	0.61	0.53	1.37
D	0.32	0.28	0.96
E	1.75	1.52	1.21

CELLAR.

The foot of the stairs, the furnace, the coal compartment and the work bench, must all be lighted. Conditions were such in the room under consideration, that one unit located near the work bench provided maximum illumination here; and by using a

flat dome-shaped enameled metal reflector (16) with a 40-watt clear tungsten filament lamp, a wide spread of light was secured which was adequate for the other places mentioned, as is shown in Fig. 23.

The cellar was not originally lighted with electricity, and to save the cost of wiring, which would have been necessary to install a snap switch near the head of the stairs, recourse was had to the following arrangements: A ceiling switch was placed on a vertical block attached to a floor beam and a strong string was run through eyes on the ceiling, ending at a knob at the head of the stairs. To illuminate the cellar it was only necessary to pull on this knob.

Illumination Readings.—Tungsten filament lamp at 1.17 watts-per-candle. Illumination on the work bench, 3.6 foot-candles. Normal illumination 3 feet from the floor in coal compartment, 0.32 foot-candle. Normal illumination 3 feet from the floor at the furnace, 0.12 foot-candle.

PORCH.

The ceiling of the porch is of varnished pine and 9 feet (2.74 m.) in height. The front of house is painted a dull grey, the trim is white, the floor is a dull grey.

The original lighting equipment consisted of a ceiling type holder, with a globe as shown by "B," Fig. 1, and a 50-watt clear carbon lamp hung 8 feet 9 inches (2.66 m.) from the floor; it was controlled by a push wall switch in the hall.

The porch requires but a very low intensity of illumination sufficient for a person to clearly see the steps, bell and nameplate, and to be distinguished from within the entrance. The wattage should be very low, as it is often desirable to have the light burning for a long period.

One feature which is very noticeable in the average porch light, is the collection of dirt and dead insects in the bottom of the globe. This was the condition found in the present instance. An illumination test made before and after cleaning, showed an increase of illumination of 24 per cent. with the clean globe.

The lamp was replaced by a 10-watt clear tungsten filament lamp, and the globe by an opalescent enclosing ball (17) of an attractive design, roughed outside. The present illumination is

sufficient, the diffusion is excellent and the appearance of the unit is pleasing. See Fig. 24. The shadows visible on the porch surface were produced by an arc lamp burning a short distance away.

It is planned to install a weather-proof flush receptacle, so that a portable lamp may be connected for reading on summer evenings.

Illumination Readings.—Stations as indicated in Fig. 3. First three readings on a 3-foot horizontal plane; fourth reading in a vertical plane about 5 feet from the floor (illumination on the face of a person at the top of steps).

Stations	Actual illumination old equipment dirty	Illumination old equipment clean and corrected to 50 w. 2.97 w. p. c. carbon	New equipment tungsten filament at 1.40 w. p. c.
A	0.25	0.38	0.16
B	0.20	0.30	0.11
C	0.15	0.21	0.09
C	0.19	0.41	0.18

CONCLUSION.

Due to the decorative element and the question of localized lighting, it is impossible to compare the illuminating efficiency of the two systems. The total connected lighting load of the original installation was 800 watts. The present connected lighting load is 555 watts. The lighting has been reduced in certain portions where a high intensity is neither necessary nor desirable. In other rooms it has been increased. An effort has been made to produce a thoroughly pleasing installation at a reasonable cost. Diffusion and an artistic appearance have been the goal. Not a lamp is visible save in the kitchen and cellar, and even in those places the lamps are so placed that there is no glare. Little attention has been paid to the cost of operating any given lamp, but rather the size used has been chosen to give what the writer believes to be the desirable intensity.

Although the total lighting load has been decreased the revenue to the Central Station remains the same or even greater. This is more or less of a paradox, but can be demonstrated by a few concrete examples; for instance, the porch now has a 10

watt lamp in place of a 50-watt lamp. If callers are expected this is allowed to burn all evening, whereas, the larger lamp would be merely turned on and off when a person was entering or leaving. Again, the den is probably the most used room in the house. With the three small lamps in the chandelier, one or two would probably be all that would be used; whereas the indirect fixtures must be turned on in its entirety, thus requiring a load of 100 watts. The small portable lamp on the music stand in the living room creates such an inviting atmosphere that it is burned most of the time, even when the room is unoccupied.

With the realization that there is a small lighting load there seems to be a psychological effect to use the electrical conveniences: namely, the iron, toaster and percolator to a greater extent than if the lighting demand were heavy. These few illustrations bear out a point that progressive Central Stations have long realized: namely, energy consumption need not be reduced with the introduction of high efficiency lighting appliances.

The writer desires to take this opportunity of extending his thanks to Mr. E. F. Carrington, for his assistance in taking photographs and in conducting illumination tests.

APPENDIX.

LIST OF ACCESSORIES USED.

1—Alba ornamental ball frosted No. 3,655, 6″ diam., 5⅞″ deep, Macbeth-Evans Glass Co., Pittsburgh, Pa.

2—Alba semi-indirect bowl, frosted, antique finish, No. 3,629, 16″ diam., 8″ deep, Macbeth-Evans Glass Co., Pittsburgh, Pa.

3—Iris portable lamp No. 4 P.N. 19, Holophane Works, General Electric Company, Cleveland, Ohio.

4—Swing portable with slate base No. 19, The Simes Co., New York City.

5—Xtraficiency prismatic reflector XE-60, 8″ diam., 5⅝″ deep, Holophane Works, General Electric Co., Cleveland, Ohio.

6—I. P. Frink patent mirrored reflector, H. W. Johns-Manville Co., New York City.

7—Eye comfort indirect fixture No. 31R, 13″ diam., 8″ deep, reflector No. E-200, National X-Ray Reflector Co., Chicago, Ill.

8—Electric holder for indirect lighting No. 2,843, Plume & Atwood Mfg. Co., Waterbury, Conn.

9—Camia bowl reflector B-60, 7″ diam., 5″ high, Gleason Tiebout Glass Co., New York City.

10—Calla shade No. 453-56, 4¾″ diam., 5½″ deep, Holophane Works, General Electric Co., Cleveland, Ohio.

11—Druid bowl reflector No. 3,024, 6″ diam., 4¾″ deep, Holophane Works, General Electric Co., Cleveland, Ohio.

12—Half shade nickle plated No. 21, Benjamin Electric Mfg. Co., Chicago Ill.

13—Iona shade No. 1,615 E 111 grey and blue, 4″ diam., 6″ deep, Macbeth-Evans Glass Co., Pittsburgh, Pa.

14—Iona bowl No. 1,605 E 111 grey and blue, 10″ diam., 8″ deep, Macbeth-Evans Glass Co., Pittsburgh, Pa.

15—Xtraficiency prismatic reflector XE-40, 7″ diam., 5″ deep, Holophane Works, General Electric Company, Cleveland, Ohio.

16—D'Olier metal reflector No. ED-40, 12″ diam., 4¼″ deep, Holophane Works, General Electric Co., Cleveland, Ohio.

17—Alba ornamental ball frosted No. 3,661, 6″ diam., 5⅛″ deep, Macbeth-Evans Glass Co., Pittsburgh, Pa.

DISCUSSION.

MR. P. S. YOUNG: I think that indirect and semi-indirect fixtures are very desirable in the home. The home is the place, as we all know, where there should be comfort. I was impressed by the statement in the paper that true artistic effect means comfort. I think that is true, and I am very glad the paper brought out that thought. I was also impressed by the practical illustrations shown in the paper. The dwelling showed that it was occupied. So many of the papers written on home lighting do not always give that impression: they are the so-called model homes.

The use of indirect and semi-indirect fixtures should be advocated, I think, by both the electric and gas companies. We

all know that the business man's standard, when we talk to him about illumination, is the lighting of his particular home. He knows more about the lighting of his home than he does about the lighting of his place of business. He knows more things about his home anyway than he does about his place of business, whether it be factory, store, office or what not. We who are working for better illumination, I think, should bear that in mind and try to improve the lighting of residences and homes. It will have a wide-reaching effect. It goes farther than the particular business of lighting the home, although that is important.

Another point that interested me was that too much stress is not laid upon the purely engineering features of illumination. I think that is sensible. I do not want to in any way disparage the desirability of the engineering part of the work (it is absolutely essential and important), but I was glad to see the practical aspect of this problem treated in the way it was.

There is a problem about home lighting that is different than any other problem. The paper states that home lighting is like the lighting of churches and other interiors. It is like those in its decorative features, but it offers, I think, a wider field than any one of those mentioned in that each particular room in itself presents a different problem.

Mr. G. H. Stickney: Mr. Young has mentioned a point which I believe is one of the most essential in the lighting of a home; that is, that the pleasant or artistic effect is the most important consideration, while engineering, particularly as related to economies, should be secondary. In the design of a home lighting installation, without overlooking economy, we should give our main thought to securing a pleasant and cheerful lighting effect suited for the room. Any lighting which is truly artistic and suited to its conditions must necessarily be useful. If it is not suited to the use of the eye or introduces eyestrain, it can hardly be considered artistic. The greatest value of engineering in this connection is to record the conditions which give pleasant effects, in order that we may interpret existing experience in determining future installations.

Measures of intensity are often deceptive if taken alone, and it is sometimes difficult to predict what intensity will be required in a particular installation. I do not believe that 2 foot-candles

is necessarily too low an illumination to be pleasant in a living room; in fact, I have known a number of places where even a lower average intensity than that gives attractive results. Many of you have probably read the recent papers by Dr. Ives on brightness as an indication of what is pleasant in lighting. I am convinced that, in the studies which he has made he is attacking the problem by a right method, and that we are destined to obtain a great deal of valuable information by studying the distribution of brightness in the lighting effects which we, as individuals, find to be pleasant and thus determining wherein they differ from other effects which we find displeasing.

Mr. Leon H. Scherck: Some of the speakers have mentioned the artistic values of studies of this kind and others have touched slightly upon the engineering features. If you will allow me a few minutes, I should like to say something regarding the revenue end of the problem and the value to be derived from a consideration of papers of this kind.

From analyses, which I have made from reports of several companies, I have found that the use of the higher efficiency lamps in residences has made a considerable reduction in the revenue of central stations. As the prices of tungsten lamps decreased and the strength of the filament increased, a large number of residential customers, who made use of the lamps without any study of better methods of illumination, simply cut down their bills. A 50-watt lamp was replaced by a 25-watt tungsten and the bill was reduced accordingly.

The value of this paper, however, is better appreciated when we think of what will probably happen in the near future when we have lamps of even greater efficiency than the present tungsten lamp. It seems to me, that those of us who are interested in the revenue end of a lighting business should watch this development with great care, because I believe that it is possible by making studies of this kind to actually make a better satisfied customer and, at the same time, have him use equally as much energy and receive thereby better illumination.

A practical way of making use of the recommendations given, I should think, especially in the case of the smaller companies, would be to actually fit up a few homes at the company's expense and have these homes inspected by the citizens of the community.

I believe that with proper methods of illumination, no matter how great the efficiency of the lamps may become, the revenue to the central stations will be conserved.

If I can add anything at all to these papers, it will be to say that a study of the methods advocated should be helpful to us in keeping up our revenue.

Mr. A. L. Powell (In reply): When writing this paper I had in mind a query which was raised this evening: I felt the great desirability of data relating to homes of the middle class. The home described falls in this group. The bills average around $2.00 per month.

The existing outlets were used in all cases; and this explains the tone of apology which might be noticed in the description of the kitchen. I believe that satisfactory results can only be secured in the kitchen of average size by the use of more than one outlet.

Mention was made of the necessity of baseboard receptacle and closet lighting. As the paper states, the house was already wired; if I were designing the installation, baseboard outlets would have been specified where required. In this case an attempt was made to get as good lighting as possible at a reasonable cost. All the closets are of such a shape and size as to be satisfactorily illuminated by the general lighting.

One speaker expressed doubts as to the suitability of the totally indirect lighting for the den, as it tends to remove the "cozy" atmosphere. It is true that there was some hesitancy about installing this system, but the room is used a great deal for card playing. With one outlet in the center of the room, the direct system will not produce good illumination on the faces of the cards. There has been a number of non-technical people in the house, and of all the types of fixtures installed, the totally indirect has produced the most favorable comments. This may, of course, be due to the fact that its use is not widespread, and it is therefore novel.

TRANSACTIONS

OF THE

Illuminating Engineering Society

JANUARY, 1914

PART II

Miscellaneous Notes

Council Notes.

The Council held a regular meeting anuary 8, 1914, in the general office, 9 W. 39th Street, New York. In ttendance were: C. O. Bond, president; P. W. Cobb, Ward Harrison, Joseph D. srael, general secretary; V. R. Laningh, C. A. Littlefield, L. B. Marks, Preston S. Millar, Alten S. Miller, . Arnold Norcross, C. J. Russell, G. H. Stickney, F. A. Vaughn; and Bassett ones, Jr., and Norman Macbeth upon nvitation.

President Bond called the meeting to rder at 2.35 P. M.

The minutes of the December meetng were amended slightly and adopted.

A report from the Finance Committee (Mr. C. A. Littlefield, chairman) ealing for the most part with a budget or the present fiscal year was discussed t length. The revenue was estimated t $12,450; the expenses $12,000.

It was voted to keep the account of ne Society at the Lincoln National ank, East 42nd Street, New York, hich has agreed to allow 2 per cent. nterest on 75 per cent. of the daily alance.

Resolved that the Finance Committee e asked to consider the question of etermining what per cent. of the revene of the Society should be derived om sustaining members.

Voted to authorize payment of Demher vouchers, Nos. 1549 to 1585 inusive, amounting to $1,107.72.

Mr. Israel reported briefly on the embership and society affairs.

Mr. G. H. Stickney in oral report of ogress for the Lighting Exhibit Comittee said that the Society had been varded a grand prize (diploma and edal) for the exhibit which was disayed at the International Exposition Safety and Sanitation, Grand Central Palace, New York, December 11-20, 1913, and which is to be installed permanently in the American Museum of Safety, 29 West 39th Street, New York.

Voted, that expenses of the Committee over its fund be paid by the Society upon approval of the Finance Committee.

A written report was received from the Committee on Editing and Publication. The report contains four proposals, the adoption of which, it is believed, would increase the value of the TRANSACTIONS; it will be considered at the next meeting of the Council or its Executive Committee.

A written report of progress, a synopsis of which follows, from the Committee on Education was received and accepted.

In general it would appear from the views of the members of the Committee that any unsolicited effort to secure the establishment of courses in illuminating engineering leading to the degree of Illuminating Engineer would be premature and that the Committee should undertake this only if the Society is approached by some technical school with the request for cooperation along this line. It is felt, however, that the Committee might perform a service by preparing a provisional curriculum which could be issued upon request to technical schools and which would possibly be useful in arousing interest in the subject, though it would be premature to urge its adoption.

The effort to ascertain what is being done in technical schools along the line of illuminating engineering instruction and thesis work is regarded with approval by the members of the Committee, and the corresponding work of placing the result of such a canvass before all who are likely to be interested is an obvious course if the canvass is undertaken.

The Committee could be serviceable during the present year if it confined its efforts to the following: (1) Canvass technical schools to learn what is being done in the way of instruction and thesis work in illuminating engineering. (2) Report the results of such canvass to all technical schools, universities and colleges, including any interesting information which may be made available, such as bibliography of the subject, suggestions for thesis work, etc. (3) Prepare provisional curriculum which could

be issued in response to inquiries. (4) Communicate with school commissioners and boards of education, pointing out the importance of illumination and soliciting their co-operation in the promulgation of educational material.

Attached to the report was a list of suggestions pertaining to the work of the committee, which was compiled from various sources.

In a report presented by the Committee on Time and Place of the 1914 Convention it was recommended that the convention be held in Cleveland, O., during the week of September 21, 1914.

Resolved that the convention be held in Cleveland, the specific dates to be decided later.

That notices of acceptance be sent to the various members, organizations, and others from whom invitations to hold the convention in Cleveland have been received.

Voted that the president appoint a general convention committee.

Written reports on section activities were received from the following vice-presidents: W. J. Serrill, Philadelphia; J. R. Cravath, Chicago; J. W. Cowles, New England; oral reports were given by G. H. Stickney, New York; Ward Harrison, Pittsburgh. Mr. Stickney said that the Membership Committee of the New York Section is going to try to bring into the Society fifty new members in the course of the next month or two.

The question of having duplicates of the booths of the lighting exhibit mentioned above made for temporary display in cities throughout the country was discussed briefly.

Voted that a committee be appointed to consider the advisability of this scheme and ways and means to carry it out, the committee to present a report at the February Council meeting.

It was suggested that several of the booths might be shown in display rooms of both gas and electric companies.

The president appointed Ward Harrison, chairman; W. F. Little and Oscar Fogg.

Mr. J. D. Israel, chairman Section Development Committee, gave an informal report. He read a letter from Mr. H. E. H. Grant of San Francisco which stated that the prospects of a San Francisco or Pacific Coast Section of the Society are encouraging.

The following committee appointments were confirmed:

Committee on Reciprocal Relations with other Societies: F. Park Lewis, M. G. Lloyd and C. J. Russell.

Research: T. H. Amrine, Percy W. Cobb, E. C. Crittenden, C. E. Ferree, Walter B. Lancaster, H. Maxwell Langdon, P. G. Nutting, A. L. Powell, Wendell Reber, F. K. Richtmyer.

It was suggested that additional appointments be made.

It was stated that the present form for application for (individual) membership is a little misleading, that is, one might infer that membership in the Society is limited to persons connected with firms, companies, and institutions.

Whereupon it was decided to refer the question to the National Board of Examiners for consideration.

The meeting adjourned at 6.05 P. M.

Section Notes.

CHICAGO SECTION

The Chicago Section held a joint meeting with the Chicago Architects Business Men's Association, January 27, 1914. Mr. J. B. Jackson read a paper entitled "Planning Lighting Installations." Mr. W. A. Durgin gave the second of his series of brief talks on the fundamentals of illumination.

NEW ENGLAND SECTION

No meeting of the New England Section was held during the month of January. The next meeting will probably be held the latter part of February.

NEW YORK SECTION

Two papers, "Lighting of a Simple Home" and "Lighting a Home by Gas," were presented by Messrs. A. L. Powell and Thomas Scofield, respectively, at a meeting of the New York Section, January 8, 1914. The former paper appears in this issue of the TRANSACTIONS. About 130 members and guests were present. Thirty-five members attended an informal dinner at Keene's Chop House on West 36th Street, preceding the meeting.

PHILADELPHIA SECTION

The Philadelphia Section held a meeting at the Engineers Club, 1317 Spruce Street, Philadelphia, January 16. Dr. C. E. Ferree, professor of psychology at Bryn Mawr College, read a paper on "Deficiencies in the Method of Flicker for the Photometry of Lights of Different Colors." Dr. J. N. Rhoads gave a talk on "A Reflecting Marker for All Books." Fifty members were present. An informal dinner preceded the meeting.

The following program of meetings and papers has been announced:

SATURDAY, FEBRUARY 7.

Meeting under the Auspices of Drexel Institute.

"Light and How to Use It."

By Mr. C. O. Bond, President of I. E. S.

WEDNESDAY, FEBRUARY 18.

Joint Meeting with Franklin Institute.

"Artificial Daylight."

By Dr. Herbert E. Ives.

FRIDAY, MARCH 20.

"Lighting and Signalling Systems of Subways."

By Mr. F. D. Bartlett.

"The Sun—The Master Lamp."

By Prof. James Barnes.

THURSDAY, APRIL 9.

Joint Meeting with Franklin Institute.

"Recent Developments in the Art of Illumination."

By M. Preston S. Millar.

FRIDAY, APRIL 17.

"The Structure of the Normal Eye and its Ability to Protect Itself Against Ordinary Light."

By Dr. Wendell Reber.

"Glassware for Illumination and Other Purposes."

By Mr. James Gillinder.

FRIDAY, MAY 15.

Mass Meeting of all the Engineering Societies of Philadelphia and Vicinity.

Special Program to be arranged and to include an address on

"The Relation of Engineers to the Progress of Civilization."

By Dr. Chas. Proteus Steinmetz.

PITTSBURGH SECTION

Two papers, "A Photographic Analysis of Diffusing Units with Varying Indirect Component" by E. B. Rowe and H. H. Magdsick and "The Relation of the Engineer to the Problems of Fixture Design" by A. B. Wilson and F. J. Blaschke, were presented at a meeting of the Pittsburgh Section, January 16. Both papers will appear shortly in the TRANSACTIONS. Mr. M. Luckiesh, assistant physicist of the National Electric Lamp Association, Cleveland, gave a brief lecture on "Reflection and Reflection Coefficients." Mr. C. O. Bond, president of the I. E. S., made a few remarks on the general work of the

Society. Forty-four members and guests were present.

The following program of future meetings and papers has been announced:

FEBRUARY 13TH.

"Lighting of Railroad Yards" by A. C. Cotton of the Pennsylvania Railroad and Harold Kirschberg of the Lighting Specialties Company. The authors will discuss the various elements entering into the lighting of track scales and classification yards, together with the difficulties experienced with same, and how they are best overcome.

MARCH 13TH.

"Modern Gas Lighting" by S. B. Stewart, Contract Agent for Consolidated Gas Company, Pittsburgh, Pa. This meeting will be devoted to the discussion of gas arcs as applied to modern illuminating systems. A number of prominent manufacturers and operators will be present and take part in the discussion.

APRIL 17TH.

"The Development of Flame Carbon Arc Lamps" by C. E. Stephens, Westinghouse Electric & Mfg. Company. The author will trace the growth and development of this popular form of illuminant from its inception down to the present time, showing how the difficulties first experienced have been overcome, and its application to various fields.

New Members.

At a meeting of the Council held January 8, 1914, the following 16 applicants were elected members:

BARROWS, H. H.
Superintendent, Oakland Mazda Lamp Division, National Lamp Works of General Electric Company, 1648 16th Street, Oakland, Cal.

BEITH, R. BRUCE.
Electrical Contractor, 7015 Greenway Avenue, West Philadelphia, Pa.

BOSSI, SANTIAGO.
Calle No. 48, No. 688, La Plata, Argentine Republic.

BROWN, JAMES A.
Assistant Treasurer, Laco-Philips Company, 131 Hudson Street, New York, N. Y.

CHAPIN, HAROLD CANNING, PH. D.
Research Chemist, National Carbon Company, Cleveland, Ohio.

DICKER, ALFRED O.
Illuminating Engineer, Commonwealth Edison Company, 120 West Adams Street, Chicago, Ill.

DICKERMAN, JUDSON C.
Chief of Bureau of Gas of the City of Philadelphia, Room 332, City Hall, Philadelphia, Pa.

DURFEE, C. G.
Superintendent, Electric Meter and Arc Lamp Departments, Rochester Railway & Light Company, Rochester, N. Y.

HASLAM, R. T.
Chemical Engineer, National Carbon Company, Cleveland, Ohio.

KLISE, C. A.
Assistant to Mr. J. R. Cravath, 1649 Marquette Building, Chicago, Ill.

LITTLEFIELD, HARRY J.
Electric Commercial Agent, Queens Borough Gas & Electric Company, 345 Central Avenue, Far Rockaway, N. Y.

MILLAR, HAROLD H.
Inspector in Charge, Electrical Testing Laboratories, Box B, 30 Center Street, West Lynn, Mass.

RICHTMYER, F. K.
Assistant Professor of Physics, Cornell University, Ithaca, N. Y.

TUCKER, RICHARD B.
General Manager, Norfolk Building Supplies Corporation, 112 Brooke Avenue and 111 Tazewell Street, Norfolk, Va.

WADE, EDWARD C.
Supervisor of Street Lighting, Street Lighting Service, City Hall, Boston, Mass.

WOOD, DR. CASEY A.
Oculist, 7 West Madison Street, Chicago, Ill.

1914 Convention of I. E. S.

The eighth annual convention of the Illuminating Engineering Society will be held in Cleveland, O., probably during the week of September 21, 1914.

Index for Vol. VIII

The index for Volume VIII of the TRANSACTIONS is in the course of preparation. It will be mailed with issue No. 4 (April) of Volume IX.

TRANSACTIONS
OF THE
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VOL. IX | NUMBER 2 | 1914

THE DESIGN OF COMBINATION FIXTURES.

BY CLARENCE A. PETERSON

Synopsis: In the following paper some of the possibilities in the design of combination gas and electric fixtures are discussed and illustrated. Special reference is made to the design of ornamental gas lighting fixtures. Diagrams of a gas burner adapted for such fixtures, and of its light distribution, are given. Brief mention is made of the application of the different styles of fixtures to certain large interiors.

In dealing with lighting installations, it is important that the fixtures be designed with reference to their appearance as well as to their utility.

For commercial installations, such as offices and other working spaces, the main object is to furnish a certain intensity of light (seeing value) on the working plane. If the installation gives a high illuminating efficiency and good optical effects, the system is called successful whether or not the fixtures possess beauty or artistic merit.

The extent to which the comfort of the eyes deserves consideration should depend very largely upon how the eyes are used. Rooms constantly occupied by persons doing clerical work or labor demanding close attention of the eyes, require a different treatment than lobbies, concourses or similar places used principally for passage, and in which the eye is seldom subjected to the strain of close application, except for very short periods.

In all cases, however, the more obnoxious features of eye discomfort, such as glare from exposed or over-brilliant light sources, should be avoided because they have neither artistic merit nor economic value.

In buildings of a monumental character, however, the esthetic considerations are quite naturally foremost, and regarding these, it is not possible to give hard and fast rules. Special attention must be given to the fixture design as well as to the method of directing the light in order to bring out the effects intended by the architect. Fixtures for this class of work must give good illuminating results and also be of porportions and style to harmonize with the decorations, and present an appearance of being an integral part of the architectural treatment. In order to accomplish this, attention must be directed to the style of architecture, the proportion of the fixture, the position of the light source with respect to the room, and the character of the lights used.

A fixture suitable for a room finished in French Rennaissance, for instance, demands quite different detail from one for the Gothic style; see Figs. 1 and 2. Fixtures for Colonial finish on the other hand, may have similar ornamentation to the Classic style, but is differentiated from the latter by its more delicate proportions and detail.

The relative size of the fixture parts must be determined not only according to the size of the room, but must also be governed by the number in the room and the distance between them. A room say 20 ft. square will require a fixture of comparatively large proportions if only one is used, while if four are used the proportions will be greatly reduced, the arms made shorter and the lights mounted nearer the ceiling. For commercial lighting, the choice in the number of fixtures is governed generally by the number of occupants in the room and the use to which the room is put.

In the common systems for direct lighting, in which the lamps are suspended from ceiling fixtures, it will be found that the distribution obtained from extensive or intensive types of satin finish prismatic, or medium density opal reflectors will illuminate walls and ceilings to a sufficient degree, and the direction of the light and the arrangement of light and shade will usually be satisfactory under those circumstances. The use of reflectors giving a very small amount of light in the upper hemisphere is generally not desirable.

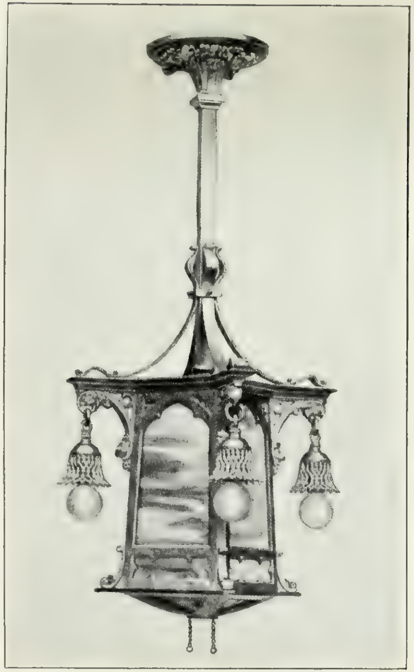


Fig. 1.—Gothic style combination fixture.

Fig. 2.—French style combination fixture.

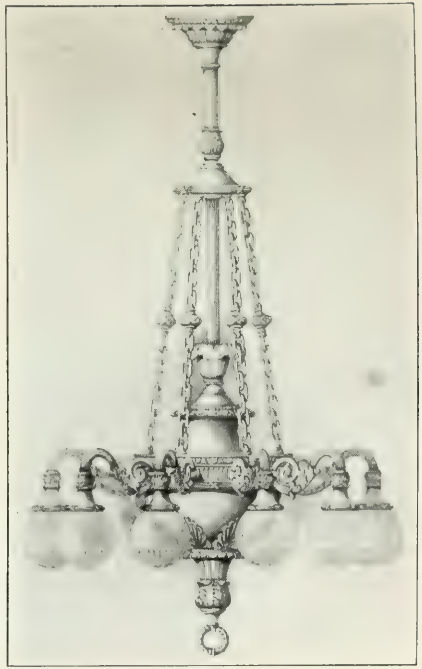


Fig. 3.—Fixture suitable for a classic interior.

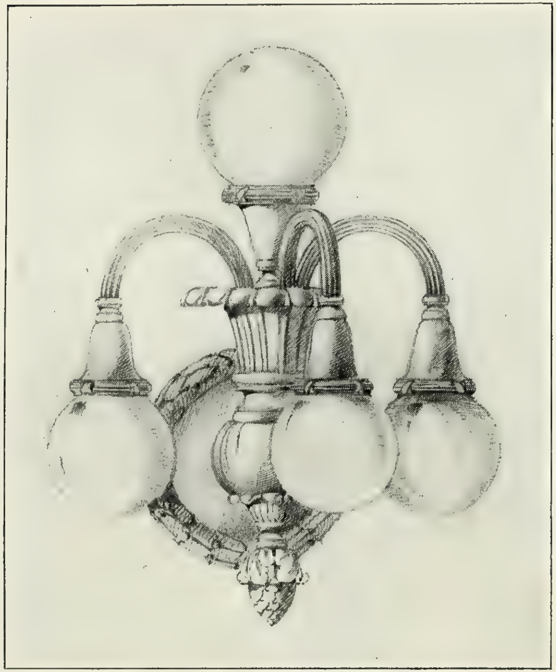


Fig. 4.—Side fixture for classic interior.

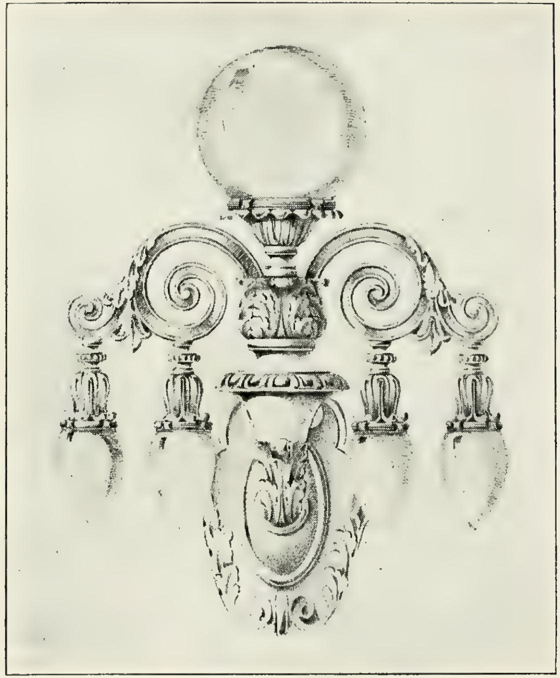


Fig. 5.—Side fixture for classic interior.

Ball globes are quite satisfactory, although they are somewhat inefficient with reference to the illumination of the lower hemisphere.

The different forms of indirect and semi-indirect lighting afford excellent methods for showing detail and general effect of interior decorations. Discretion must be exercised, however, in using either of these systems. The light source must be located properly with respect to the reflector in order to light the ceiling uniformly. And the fixtures should always be readily accessible for cleaning since dirt accumulates rapidly and affects the efficiency a great deal more than it does for direct lighting. For this reason they should not be used for high ceilings unless provision is made to lower the fixtures for cleaning.

The position of the light source, that is, the mounting height

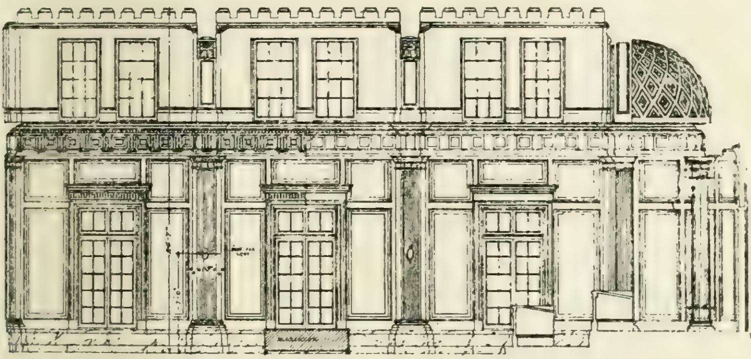


Fig. 6.—Elevation of a room having classic detail.

of the lamps and the location of the outlets, is governed by the size of the room, the ceiling height and architectural treatment. In the first place, the outlets must be so located that it is possible to provide fixtures which will direct the light in a proper manner to bring out the architectural features. For instance, with a pannelled or vaulted ceiling; if a fixture is not placed in each bay, care must be exercised to avoid an unevenly lighted ceiling. Each case requires special consideration in this respect.

Figs. 6 and 7 show two elevations of a room having Classic detail. This room could no doubt be lighted to good advantage by semi-indirect fixtures, but as these fixtures would have to be

placed near the ceiling, making them inaccessible for cleaning, a type of fixture shown in Fig. 3, mounted at about the height of the cornice would be more suitable and at the same time give

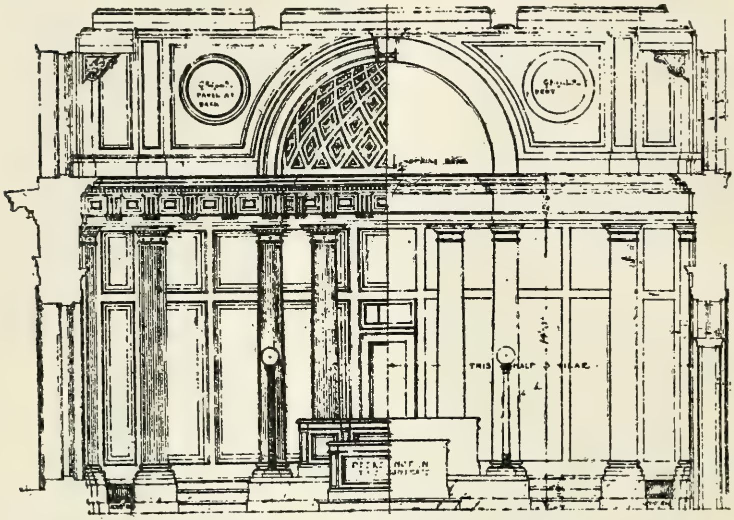


Fig. 7.—Elevation of same room shown in Fig. 6.

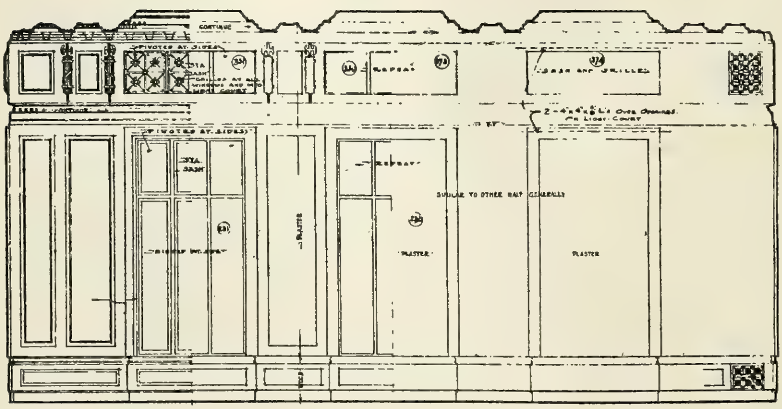


Fig. 8.—Elevation of room adapted to semi-indirect lighting.

a very satisfactory distribution of light. Figs. 4 and 5 show type of brackets suitable to supplement the ceiling fixtures.

Fig. 8 illustrates another room having a lower ceiling and the cornice nearer to the ceiling. In this case semi-indirect fixtures could be used to good advantage.

Another important feature is the treatment of the light source. A light of high intrinsic brilliancy, while being more spectacular, is generally not desirable. The eye will invariably fix itself upon the brightest spot and this will detract from the general effect. Those who have observed lighting fixtures with a cluster of bright lamps exposed to the field of vision have no doubt realized that attention is directed mainly to the lights and the architectural beauty of the room is lost.

The choice of illuminants is governed by reliability, economy of operation and convenience in control.

Reliability of service is of the utmost importance, but rarely receives consideration until a supposedly dependable service in this respect is put out of commission by an unforeseen contingency. The provision of combination fixtures, therefore, may be regarded as an insurance against interruption and is amply justified upon these grounds alone.

The installation of parallel systems with combination fixtures insures absolute reliability of the lighting service, permits taking advantage of probable future reductions in the cost of either illuminant which may change the weight of economical advantage from one to the other; and such systems should always be installed where economy of operation and reliability of service is important.

While the performance of both gas and electric lamps is seriously affected by variable conditions of energy supply, the bearing of this matter upon the selection of illuminants is quite different in the two cases. Electric lamps though suffering a reduction in light output from decreases in voltage, are not permanently impaired, nor are the means of control interfered with. Gas mantles on the other hand, when furnished with gas of varying specific gravity or at irregular pressure, are apt to accumulate carbon, which can only be burned off by readjustment of the lamps. Furthermore, the pilot system of ignition, by which remote control is made possible, requires a gas supply varying but

slightly in pressure and quality, otherwise pilot failures demanding frequent attention are apt to occur.

The actual operating economies of gas and electric lamps depend very largely upon the quality of service as well as upon the cost of the illuminants. While fluctuations of electric voltage produce much more serious effects than fluctuating gas pressure (as far as efficiency of light production is concerned) the electric voltages are much more closely regulated and good service conditions are far more prevalent than with the gas. Both gas and electric companies, however, are lately paying more attention to the subject of supply service; but the electric companies have shown a greater willingness to appropriate money for the improvement of their service in this particular than have the gas companies, although the latter are able to accomplish the desired result more easily and more cheaply, since it is possible to use inexpensive governors which regulate the pressure within very narrow limits. The lack of such governors is responsible for many of the causes of unsatisfactory gas lighting and pilot service. In all cases where a uniform pressure cannot be maintained, pressure governors should be furnished as a necessary feature of the service. To obtain the best results, it is just as important for the gas companies to furnish their product at a uniform pressure as it is for the electric companies to furnish energy at a constant potential.

The maintenance of glassware in good condition deserves much more attention than it usually receives. Accumulations of dirt on gas and electric glassware seriously effect their light giving qualities and cleaning should be done at regular intervals. It is rather a curious fact that windows will be regularly cleaned to let the light in, but the lamps will not be cleaned to let the light out.

Gas lamps properly adjusted to begin with, and furnished with clean gas at uniform pressure and quality, and fitted with good mantles will require very little attention, and it has been the writer's experience that under good conditions of service supply, there is little to choose between the maintenance labor required under the use of either illuminant.

While a light source is always attractive there is no natural

desire to see the mechanism by which it is produced. Therefore to provide fixtures having artistic merit, it is necessary to con-

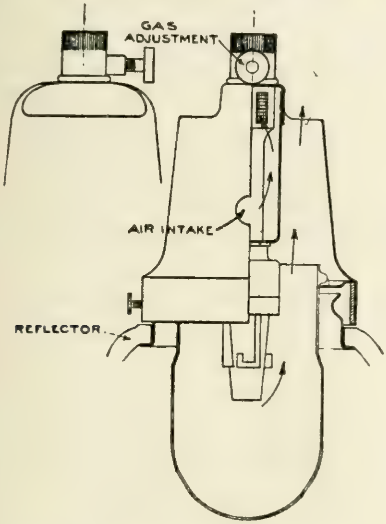


Fig. 9.—Sectional view of a gas burner.

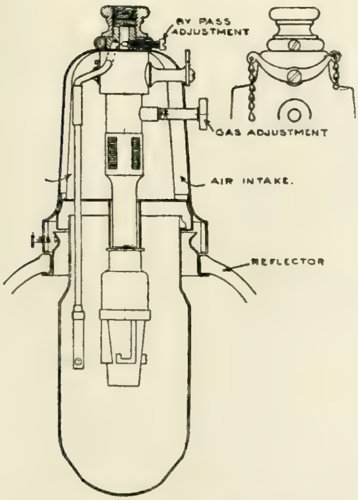


Fig. 10.—Sectional view of a small self-lighting gas burner.

ceal the operating mechanism of the lamps. To accomplish this on combination fixtures, a new type of gas burner has been

developed. Fig. 9 shows a half sectional view of one of these burners. The body consists of a one piece casing of same size and design as the electric socket covers used. Two openings are provided near the top for the passage of the products of combustion. The casing incloses the air chamber containing a mixing tube, gas regulating valve, and mantle of a well known type. Reflectors are provided having the same height and substantially the same shape as those used for electric lamps. Such reflectors are made in both the intensive and extensive types in order that the same distribution of light may be obtained as with the electric units.

Cold air enters the air chamber at the openings shown and is

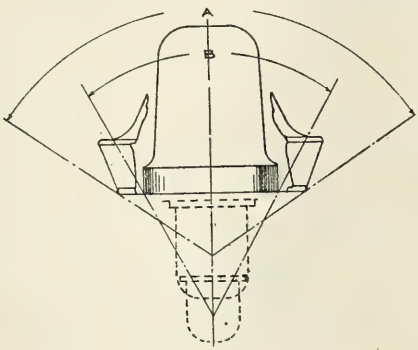


Fig. 11.—Comparison of light absorbed by the common and a newly designed burner. Zone of angle A is about four times that included by angle B.

heated before passing into the mixing tube. This arrangement in connection with the unobstructed path provided for the products of combustion tends to insure a good draft and perfect combustion. Since the air chamber is entirely inclosed and the intake openings are located below the vents, the intake air is free from contamination by the vent gases, thus affording a clean burner requiring very little attention.

This burner will give about the same candle-power as a 60-watt lamp, but it can also be used with a 25 or 40-watt lamp without affecting the symmetry of the fixture. It is well suited for brackets, or pendants where a by-pass is not desired.

A modification of this burner (see Fig. 10), has the by-pass cock, pilot tube and gas regulating valve concealed within the

Fig. 12.—A fixture designed along plain lines.

Fig. 13.—Adaptability of a gas burner to an ornamental fixture.

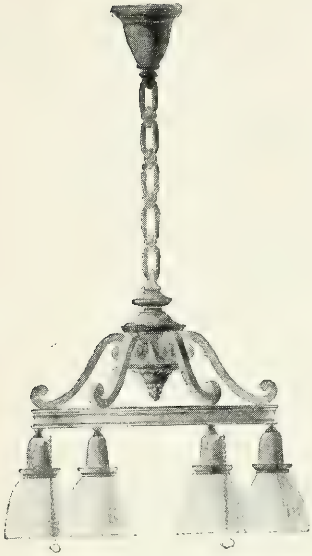


Fig. 14.—A fixture with alternate gas and electric units.

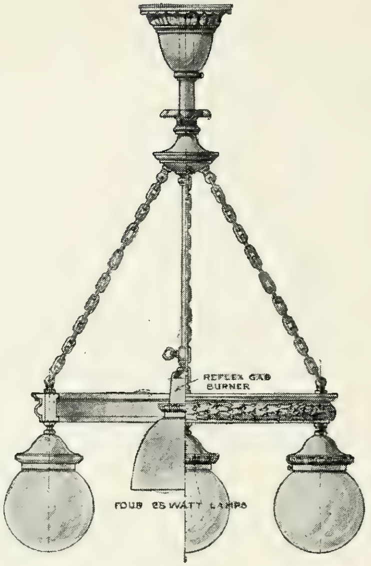


Fig. 15.—A fixture having a gas burner in the center of four electric units.

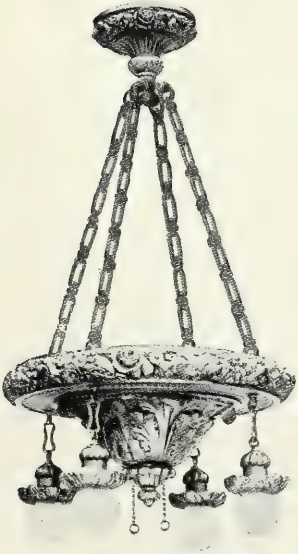


Fig. 16.—A fixture adapted to gas and electric units.

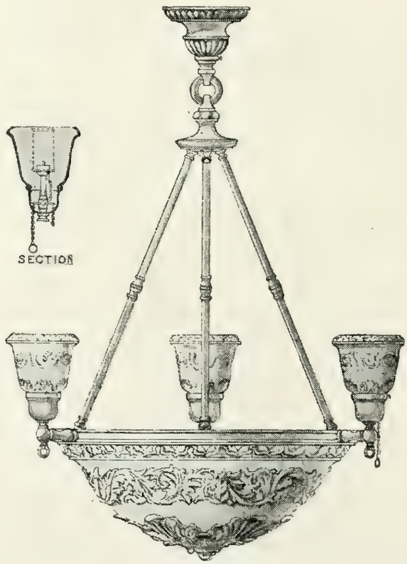
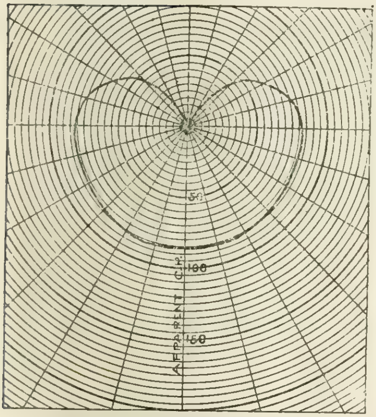
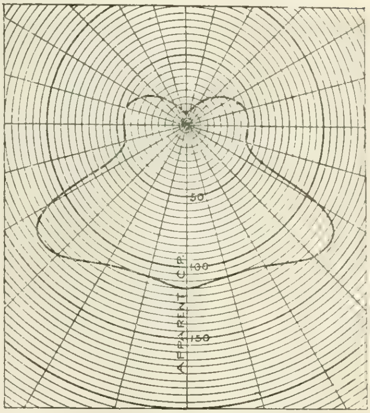


Fig. 17.—A combination gas and electric semi-indirect fixture.



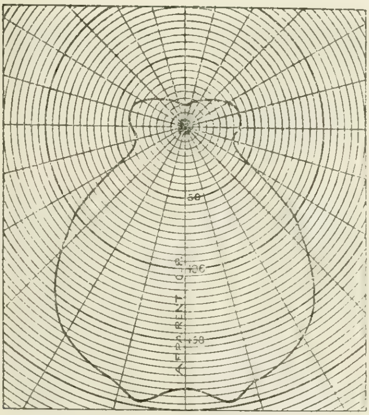
MEAN VERTICAL DISTRIBUTION OF LIGHT
ABOUT
REFLEX GAS BURNER
WITHOUT REFLECTOR.
PRES. 2.5" CONS. 2.50 WATER GAS.
664 B.T.U. SP. GR. .631
C.P. 55.2 346.8 LM.
C.P. 82.4 517 7 LM.
C.P. 68.8 864.5 LM.

Fig. 18.—Mean vertical distribution of light about a bare gas burner.



MEAN VERTICAL DISTRIBUTION OF LIGHT
ABOUT
REFLEX GAS BURNER
WITH SATIN FINISH PRISMATIC REFLECTOR
PRES 2.5", CONS 2.61 WATER GAS
653 BTU, SP. GR .625
C.P. 34.6, 217.4 LM
C.P. 86.6, 544.1 LM
C.P. 60.6, 761.5 LM.

Fig. 19.—Mean vertical distribution of light about a gas burner equipped with an extensive satin finished reflector.



MEAN VERTICAL DISTRIBUTION OF LIGHT
ABOUT
REFLEX GAS BURNER
WITH SATIN FINISH PRISMATIC REFLECTOR
PRES. 2.5" CONS. 2.46 WATER GAS
B.T.U 664 SP. GR. .631
C.P. 32.0 210.0 LM
C.P. 86.8, 545.4 LM
C.P 59.4 746.4 LM

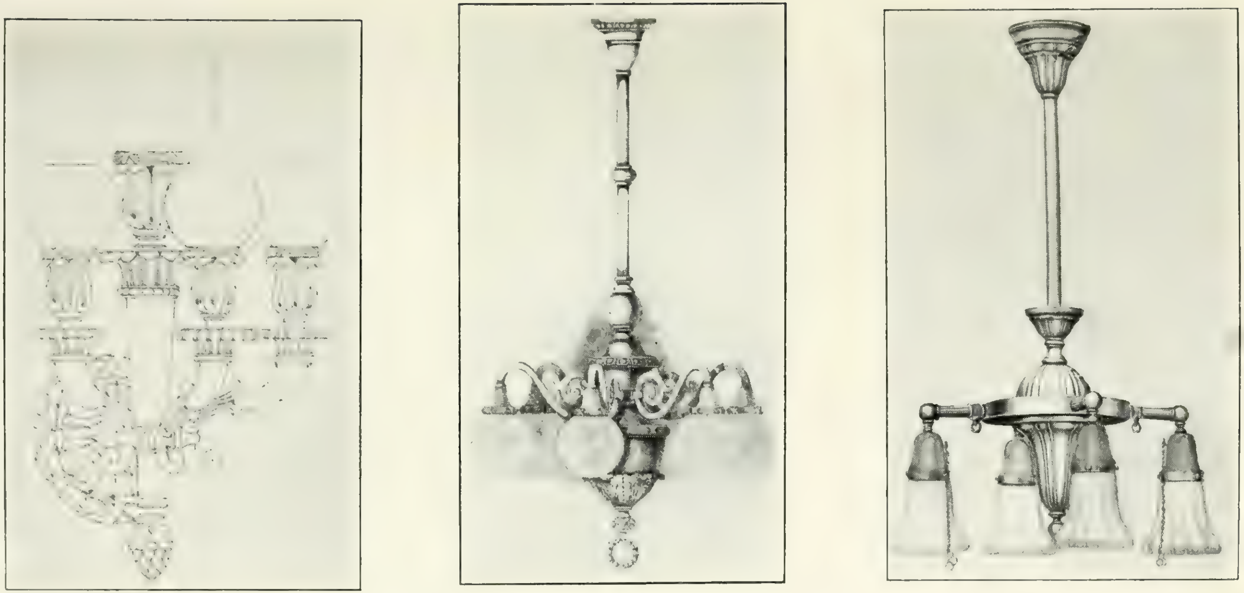
Fig. 20.—Mean vertical distribution of light about a gas burner equipped with an intensive prismatic reflector.

burner body or casing in such a manner that all adjusting parts are accessible. This light is of higher candle-power than the former and gives about the same quantity of light as a 100-watt lamp. The purpose of this design is to produce a self-lighting burner of a comparatively small size without reducing its light giving capacity, to have a body of practically the same size and shape as the usual form of casing inclosing an electric socket, and which will receive a reflector or globe harmonizing with the electric glassware on units of about the same candle-power. Like the 60 and 100-watt lamps it takes a reflector having a 2¼-inch diameter collar. On account of its small holder and low mantle position, this burner intercepts a very small zone of light; whereas a great many inverted lamps have the mantles so high and the holder so large that a great deal of the light flux of the upper hemisphere is absorbed; see Fig. 11. The favorable results of this construction are shown by the photometric curves obtained which are discussed later.

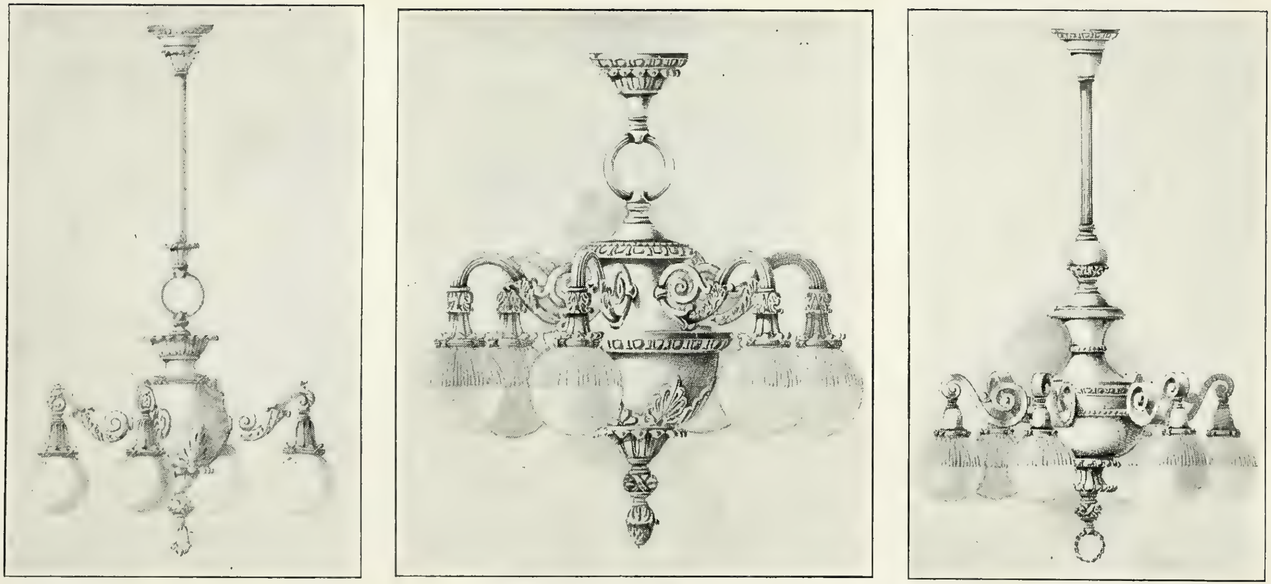
There is no air supply regulator for these burners. The writer has found that the great majority of users of mantle burners know very little about adjusting them. Two adjusting members, that is, the air supply and the gas supply buttons, are rather confusing and frequently the air supply is cut off when it should be opened. With the air opening fixed, only one adjusting button is used and it becomes a simple matter for even the inexperienced to adjust the gas supply for giving the maximum light.

A few illustrations are shown of this burner mounted on combination fixtures. Fig. 12 shows a fixture of rather plain lines. This picture illustrates how well the gas unit harmonizes both in size and in outline with the general design of the fixture. It will be observed that the burner is free from unnecessary lines and perforations, is symmetrical with the electric parts and presents an appearance of being an integral part of the fixture.

Fig. 13 indicates the adaptability of the burner to a fixture of more elaborate style. The burner is made to harmonize with the general design of the fixture by fitting to it an ornamental holder. It indicates how readily the treatment can be varied to suit architectural conditions or individual tastes.



Figs. 22, 23, and 24.—Fixtures well adapted to use of gas and electric light units.



Figs. 25, 26, and 27.—Designs of fixtures suitable for gas and electric light units.

Figs. 14 and 15 are designs of the cluster type. In Fig. 15, the gas burner is placed in the center of four 25-watt lamps fitted with globes, while in Fig. 14, the gas and electric lamps alternate. The chain effect stem of the latter is made of continuous tubing bent to shape and fitted with ornamental cast pieces to complete the appearance of links. These fixtures as well as the others shown have the same light giving capacity with either illuminant. The advantage of such a feature affords the use of either illuminant separately with substantially the same results.

The semi-indirect fixture, Fig. 17, embodies a common form of electric opal bowl and three upright mantle burners provided with internal pilot tips. The gas reflectors used are of a commercial type and harmonize quite well with the electric dish. The pilot flame, being located in the center of the mantle, is protected from air currents and is very reliable in operation. The burners each consume about 1¾ cu. ft. of gas per hour and give a light equivalent to that of about 175 watts of electric energy.

It is obvious that the use of well designed fixtures affording dual service has its advantages over either service separately. While the availability of electric service during the summer months is highly desirable, both for fan service and intermittent lighting for comparatively short periods; the gas service for the winter months when good light is needed for longer hours, is more desirable in many respects.

That the burners herein shown are superior in efficiency as well as in appearance will be evident by referring to the photometric curves. Fig. 18 indicates the light emitted by the larger unit. At a consumption of 2.5 cu. ft. per hour, it gives the high value of 345 lumen hours per cu. ft. of gas consumed, which is from 40 to 50 per cent. more than that given by the average run of mantle burners.

The curves of Figs. 19 and 20 showing the burner with intensive and extensive types of satin finish prismatic reflectors, have all the characteristics desirable for direct illumination. The greater portion of the light is directed downward within an angle of 60 degrees from the vertical axis, the horizontal flux is low

and the flux in the upper hemisphere is small but sufficient to prevent a gloomy appearance of the ceiling.

Figs. 22 to 27 are given as types of fixtures which will lend themselves very readily to the use of combination units, without effecting their artistic elements.

THE ESSENTIAL ELEMENTS OF VISION.

BY HUNTER H. TURNER, M. D., PITTSBURGH, PA.

Synopsis: The paper treats of (1) the structure of the eye; (2) the action upon the eye of lights of different color and intensity, (3) theories of color vision.

I.—STRUCTURE OF THE EYE.

The eye is not only an extremely complicated optical instrument, a camera obscura, but its recipient, recording element is a living tissue, so wonderfully and delicately specialized, that the untiring efforts of our most highly developed physicists and physiologists, applied assiduously over a period of many years, have hardly sufficed to secure even the most superficial knowledge

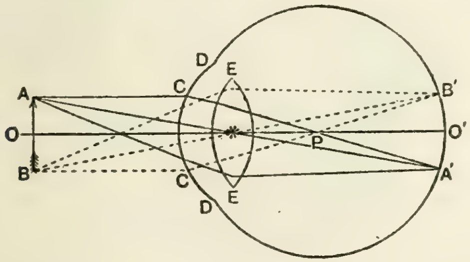


Fig. 1.—A diagram showing how rays of radiant energy entering the eye are so refracted as to form upon the retina an inverted image of the object.

of the obscure processes whereby the vibrations of radiant energy, passing through the transparent refracting media and falling upon the retina, are converted into such form of energy as is capable of producing in the cerebral centers the physiological phenomenon known as vision, with its variations as to light and darkness, color and luster.

The retina, which contains the specialized nerve endings whose secret has so largely defied scientific research, is the innermost tunic of the eye-ball. Formed by an outgrowth from the brain,

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its structure is in many respects analogous to that of the cerebral cortex. It must therefore be regarded as a true nerve center and as a peripherally situated portion of the central nervous system, rather than as merely the complex recipient apparatus of radiant energy.

The active retina extends forward from the optic nerve entrance, or optic disk and covers the posterior three-fourths of the inner surface of the tunic external to it, although the pigment layer is continued anteriorly to the margin of the pupil.

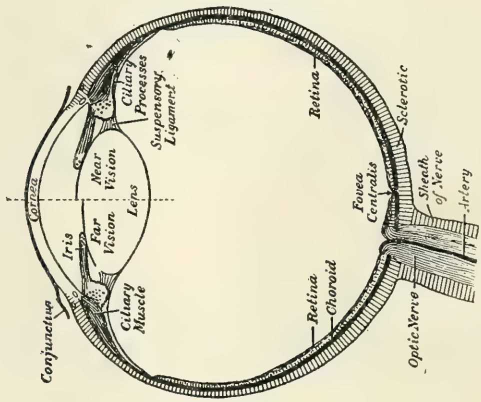


Fig. 2.—A diagram of the eye.

It is a delicate, smooth membrane, so perfectly transparent that in health it can be distinguished only, by its blood-vessels, which seem to float within its substance. When deprived of light for a time it assumes a purplish red tint, very evanescent under the action of light, which is due to the presence of a pigment known as rhodopsin or "visual purple."

The two tunics external to the retina which invest the posterior portion of the eye-ball, the choroid and sclerotic tunics, have no active part in the production of vision, their functions being principally those of nutrition and protection, respectively.

The active retinal nerve elements may be divided into three types of specialized cells, arranged in stratæ which are, from

without inward, the layer of rods and cones, *a*. (Fig. 3), in which the nerve stimuli originate; the layer of bi-polar cells, *b*, which conduct the stimuli from the layer of rods and cones to the large multi-polar, ganglion cells, forming the third layer, *c*, whose axis cylinder processes pass by way of the nerve fiber layer, to become component fibers of the optic nerve.

These elements, with the exception of the rod fibers, terminate in fine arborizations which osculate with similar arborizations of the cell adjoining in the chain of nerve elements, the arborization not being continuous with those of the associated element.

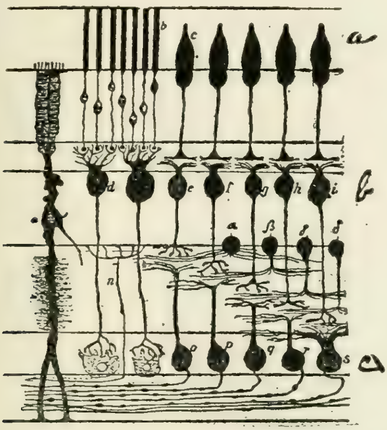


Fig. 3.—A diagram showing the three types of specialized nerve cells and their arrangement relative to each other.

The retina is composed of ten layers which are from within outward, the internal limiting membrane, the nerve fiber layer, the layer of ganglion cells, the inner molecular layer, the inner nuclear layer, the outer molecular layer, the outer nuclear layer, the external limiting membrane, the layer of rods and cones, and the pigment layer. The internal and external limiting membranes are purely structural in character and are formed by the junction laterally of the sustenacular fibers of Muller; the inner and outer molecular layers are simply stratæ of a structural

substance known as neuroglia, in which the terminal arborizations of the cellular elements osculate.

The neuro-epithelial layer contains the rods and cones which are the active elements of the retina and are arranged at right angles to the external limiting membrane.

Each rod is made up of two parts, very different in structure, called the outer and inner limbs. The outer limb is cylindrical, is about 30 microns in length and 2 microns in diameter, is trans-

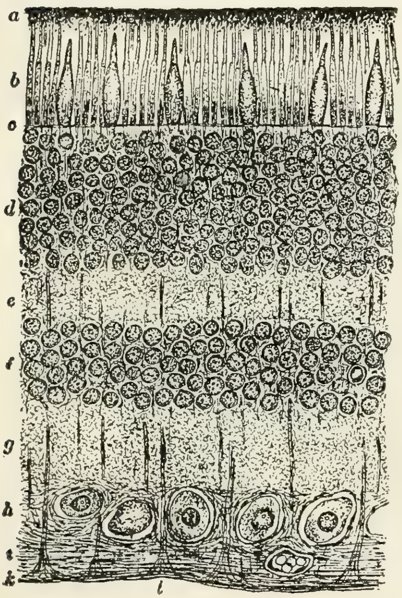


Fig. 4.—A microscopical section of the human, retina, showing the ten layers from without inward.

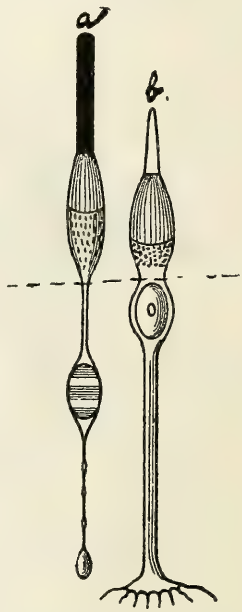


Fig. 5.—Diagram showing structure of rods and cones.

parent and doubly refractive. It is said to be composed of fine super-imposed disks. In this portion of the rod is found the pigment known as "visual purple" or rhodospin. The inner limb is also about 30 microns in length but broader than the outer limb and is slightly eliptical. It is longitudinally striated in the outer portion and granular in its inner portion.

Each rod is connected internally with a rod fiber, a very fine protoplasmic process, in the middle of which is a "rod granule," really the nucleus of the specialized cell known as a rod. It has broad, transverse striations and is situated at about the middle of the external nuclear layer. The internal end of the rod fiber terminates in a small bud-like process which osculates with the outer terminal branches of a bi-polar cell.

Each cone, like the rods, is made up of two limbs, outer and inner. The outer limb is tapering, not cylindrical like the corresponding portion of the rod and about one-third of its length. There is no "visual purple" found in the cone. The inner limb of the cone is broader in the center, is longitudinally striated in its outer portion and granular in its inner portion and under the influence of light has been seen to execute movements shortening in the presence of light and again elongating after the light is withdrawn.

Each cone is in connection internally with a cone fiber, which has much the same structure as a rod fiber, but is much stouter and has its nucleus quite near the external limiting membrane Its inner extremity terminates in fine arborizations in the external molecular layer where it osculates with the terminal arborizations of a bi-polar cell.

The pigment cell layer, the most external of the retinal layers, consists of a single layer of polygonal cells, mostly six-sided. Each cell consists of three parts, an outer zone, containing the nucleus, wanting in pigment, and presenting a smooth surface toward the choroid; a middle zone, deeply pigmented, and sometimes known as the "base" of the cell; and an irregular inner zone, consisting of indefinite protoplasmic processes, which extend between the outer segments of the visual cells, whose ends are thus received within the pigment layer. The source of the color within the retinal epithelium is in the blood, from which the substances, in a state of solution, are deposited within the protoplasm of the cells. Mays, by the use of a 10 per cent solution of HCl, and a 5 per cent. solution of sulpho-cyanide succeeded in obtaining a characteristic iron reaction. The pigment granules occur in the form of minute crystals, their long

axes being placed generally, at right angles to the retinal free surface.

At a point corresponding to the posterior pole of the eye-ball is the macula lutea or yellow spot of Sommering, in the center of which is the fovea centralis which is more sensitive to colored light than any other portion of the retina. Towards the center of the macula lutea all the layers of the retina become greatly thinned and almost disappear, excepting the rod and cone layer; in the fovea centralis, in man, the rods have disappeared entirely leaving only cones, which are here long and narrow, especially the inner segments, and have been estimated to number in the neighborhood of 13,000. At the margin of the fovea the layers increase in thickness and in the macula are thicker than in

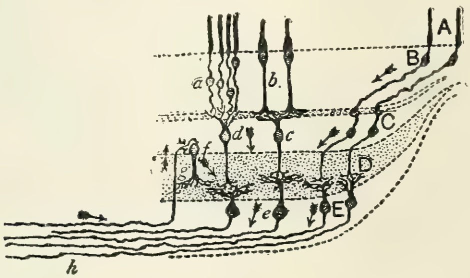


Fig. 6.—Diagram showing the obliquity of the elements in the macula lutea.

the rest of the retina, the macula standing out above the surface of the surrounding retina. This is owing to the obliquity of the cone fibers and their corresponding bi-polar cells which are comparatively massed in the macula surrounding the fovea.

In man the rods are far more numerous than the cones. From the fovea centralis, where only cones are found, outward through the macula, where both rods and cones are found, the cones far outnumbering the rods, the cones rapidly diminish in frequency and cease altogether before reaching the outer limits of the functionating retina.

The total number of cones in a given eye has been estimated to be from 3,000,000 to 7,000,000, while the number of rods has been estimated to be as high as 130,000,000. As the fibers of the

optic nerve have been estimated to be not more than 1,000,000, it is evident that the stimulus originating in *several* of the cells composing the deeper retinal layers must pass to the cerebrum through a common nerve fiber, excepting only the cones of the fovea centralis, each of which is believed to have its own individual nerve fiber, forming a special group of nerve fibers known as the maculo-papular bundle.

The nerve fibers themselves play only the part of conductors.

II.

Light is not a physical quantity, but is the physiological effect produced in the cerebral centers by a nerve stimulus, arising in the retinal structures, which has its origin in the action of radiant energy upon retinal elements, with the production of energy of such character as is capable of exciting the nerve centers after transmission along nerve pathways. We perceive light that has entered the eye, only after it has reached the retina and acted upon the layer of rods and cones, which send their special impulse to the cerebral centers.

Light does not exist for us apart from vision, in the absence of which the world becomes wrapped in darkness. The beauties of nature, with their varied forms and inimitable color effects are due, not to the physical cause but to the wonderful functionating of the retinal elements, which have the power to select radiations of definite rapidity of oscillation and by their action to produce mental effects of wonderful beauty and variety.

Radiant energy is a vibratory motion of a hypothetical medium, the ether, which is propogated through space at the velocity of about 186,000 miles per second, the vibrations of which strike the retinal tissues at the almost inconceivable rate of from 400 to 800 billion times per second. The oscillations of the radiant energy of the visible spectrum vary from a frequency of 400 billions per second, with a wave-length of about 750 microns, when they become appreciated by the visual centers as red, through gradually increasing frequency and gradually diminishing wave-lengths, which produce successively the sensations of orange, yellow, green, blue, indigo, and finally violet, when the

oscillations have acquired the frequency of about 800 billions of times per second and a wave-length of about 380 microns.

Beyond the red end of the spectrum are still other waves, invisible to us, of lesser frequency and greater wave-length, which affect us as heat and are known as ultra-red, or radiant heat waves; beyond the violet end of the spectrum are still other invisible waves of yet greater frequency and shorter wave-length, which are known as ultra-violet, actinic, or chemical rays, which owing to their power of producing chemical change, are extremely irritant to living tissues. The actinic effect is not an exclusive property of the ultra-violet rays, but belongs, in a smaller degree, also to the luminous vibrations.

The ultra-violet rays are not perceived for two reasons: first, because they are almost totally absorbed by the cornea and crystalline lens and, second, because the retinal structures are largely insensible to them. Tyndall expressed the hope that as the race becomes more perfectly developed, we may later be enabled to see these thermic and actinic rays and so enjoy wonderful sights now hidden from us.

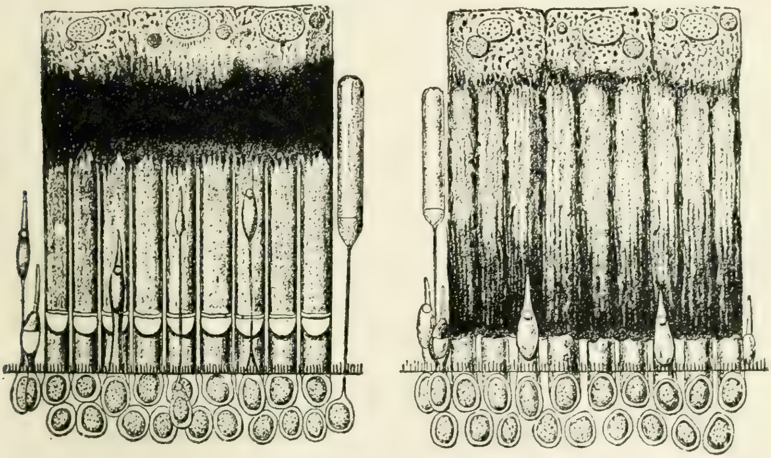
All the mediæ of the eye are uniformly permeable to rays having wave-lengths of from 660 to 380 microns. Rays having wave-lengths of less than 350 microns are absorbed completely by the cornea and crystalline lens. Widmark states his belief that this absorption produces injury to the lens, and Schanz and Stockhausen attribute to this condition the form of acquired cataract so frequent among glass-blowers and puddlers. However, other observers, notably Fuchs, ascribe the cataracts so frequently found in these cases to the action of the red or ultra-red rays from these molten materials that radiate luminous heat in vast quantities, which these men are required to face at close range. The cornea absorbs in general, vibrations below a wave-length of about 300 microns, and it is in consequence of this absorption that certain inflammatory conditions arise in the epithelial cells covering the cornea and conjunctiva. The ultra-red radiations are also absorbed by the mediæ, practically none, if any, reaching the retinal structures.

It will therefore be seen that the radiations composing the

visible spectrum only, are concerned in the phenomenon of vision.

Any form of energy when destroyed gives rise to an equivalent amount of some other form of energy. If radiant energy be destroyed by intercepting the radiation by the interposition of an opaque body in its path, its energy is converted into some other form of energy, usually heat. The amount of heat produced is the exact equivalent of the amount of energy contained in the radiation.

Under the stimulation of light, certain relatively gross changes occur in the retinal structures: the fine pigment particles within



A B

Fig. 7.—A—A microscopical section of a rog's retina showing how the pigment granules are massed within the basal portion of the pigment cells after 48 hours of total darkness, also the elongation of the cones. B—A section showing how the pigment granules have been carried almost to the external limiting membrane and the shortening of the cones after 6 hours exposure to daylight.

the pigment cells are carried into the fine protoplasmic extensions between the visual cells until the outer segments of the rods are buried within the pigment, the cones contract or shorten and the "visual purple" bleaches. It has been shown that this migration of pigment particles is not effected by the protrusion or retraction of the protoplasmic processes themselves, but is due rather to the displacement of the particles by currents

streaming within the cell protoplasm. After a prolonged exclusion of light, on the contrary, the pigment particles are withdrawn from the processes and become once more aggregated within the central or "basal" portion of the cells, the cones again elongate and the visual purple is restored.

Hannover was the first observer to describe colored oil globules in the retinal rods in reptiles and birds, in the latter of which he found all the colors of the spectrum and purple; Max Schultze has described red globules in the turtle; Leydig found rose and violet globules in the rods in insects; Boll observed green rods in the retina of the frog and demonstrated that in the presence of light the color appeared to bleach; in frogs exposed to strong sun-light he found that the color was quickly restored after the removal of the animal to a darkened room. However, colored oil globules are not found in the rods in the human eye. The only pigment which has been demonstrated, is the "visual purple." Kuehne demonstrated that the retinal bleaching is due to the action of light only, and that the color is not dependent upon structural relations, but upon a pigment which is decomposed by light.

III.

The process by which radiant energy falling upon the retina, is modified, or is changed into such form of energy, thermic or electrical, as is capable of exciting the visual centers, has been for many years the object of very careful and intensive scientific research and a number of theories have been advanced in the effort to explain satisfactorily the many phases and phenomena of vision.

The theory is held that the change effected by the agency of the radiant energy, which, passing through the retina proper, is intercepted by the layer of pigment cells, is in fact a thermo-chemical alteration in the protoplasm, which generates electrical or nerve energy that stimulates the specialized terminals of the optic nerve fibers and excites in the cerebral centers the consciousness of vision.

Dewar has recognized, since 1874, before the discovery of visual purple, that the action of light upon the retina is accom-

panied by the development of an electro-motive force, measureable by means of a galvanometer. Having confirmed this observation, Chatin later established the effect of obscuration on the intensity of the current and the unequal action of the different radiations. He found that the greatest electro-motive force is generated in those species in which the visual purple predominates. He, therefore, made the deduction that the generation of this electricity is through a thermo-chemical action which takes place in the visual purple under the influence of light. The theory is commonly accepted that the perception of light, without color, is owing to a stimulus originating in a chemical decomposition of the visual purple, the intensity of the sensation varying directly with the rapidity of decomposition.

It is impossible that the rods and cones should vibrate in unison with the etheral waves, which strike the retina from 400 to 800 billions of times per second, as they would generate such intense heat as would quickly destroy the delicate receptive apparatus. Many modern observers unite in the opinion that the change in the form of energy is by means of a chemical decomposition with a resulting molecular oscillation which travels up the nerve fiber to the brain. While the nerve fibers, themselves, act only as conductors, they also seem to be specialized, the stimulation of any sensory fiber, whether the stimulus be mechanical, chemical or electrical, causing only such central sensations as might originate in the region of the special sense, from which the impulse would come in the course of natural events. This is shown by a sudden blow upon the eye which produces the sensation of intense multi-colored lights. Also in case of injury to the optic nerve, in living tissue, great masses of light appear at the moment of injury. That the blow or injury to the nerve can compare to the infinitesimal ethereal vibrations no one will assert, yet they are productive of the same result.

Very little has been written as to the difference in function between the rods and cones, which have been broadly discussed as having a common function although so unlike in structure. In a very interesting lecture before the Polytechnical Society of Berlin, Dr. Lummer gave an experiment by Weber

making clear the difference in function between the rods and cones. The rods, according to his demonstration, have to do with the determination of form and brightness, without color; while the cones have to do with color perceptions.

The observations of Draper, to the effect that solids when heated to a point of luminosity, first emit a red glow, were not contested for a long time, since they agreed with ordinary daily experiences. Considerable interest, therefore, was excited when W. F. Weber showed that the red glow is not at all the first stage of luminosity. Weber took a piece of sheet platinum heated by an electric current, and after excluding all extraneous light, looked as nearly as possible toward the center of the sheet, so that any radiations arising from its surface would fall, not only upon the fovea centralis, but also upon that portion of the retina surrounding it. As soon as the platinum sheet reaches a certain temperature, about 400° C, it produces a foggy, grayish light, which appears to the eye as an unsteady gleaming, flitting to and fro. Its intensity increases with the increasing temperature of the platinum, while its appearance changes from dim gray, successively to ashen gray, yellowish gray and finally to red when the temperature has reached about 525° C. With the first appearance of the redness the last trace of grayness disappears, as does also the unsteadiness.

This observation is of especial interest as it gives some explanation of the properties of the rods and cones and their respective parts in composite vision. These ghost-like phenomena of the foggy light can be explained only by attributing entirely different functions to the rods and cones, considering them as two essential organs of vision, differing widely in their functions. Charpentier found the threshold for red to be about twice as great as that for light without color, and eighty times as great for violet as for red. Each set of retinal elements, rods and cones, acts independently of the other in transmitting its intelligence to the cerebral centers and there the effect produced is a composite one.

If the intensity of illumination be very slight, the rods only are affected and produce in the cerebral centers the sensation of

light without color and thus greatly increase the sensitiveness of vision in a dim light; as the intensity of illumination is increased the sensation of colorless light increases in direct ratio until the stimulus is increased to such a point that the cones begin to be affected, when the sensation of color is added to that of light. It is a common experience, as in twilight, that one is able to distinguish lights and the form of objects, while not being able to distinguish colors.

The fovea centralis, as stated above, is that portion of the retina corresponding to most distinct vision, the part on which the image of an object one wishes to scrutinize closely is focused. As the fovea contains only cones, the rods are not concerned at all in direct foveal vision, while in indirect or peripheral vision both rods and cones are affected. If, therefore, the intensity of illumination be not sufficient to stimulate the cones, the rods only being affected, one has the phenomenon of peripheral vision without color. Long before physiologists had reached these conclusions, comparative anatomists were led to recognize the fact, that in certain creatures the rods make it possible for an eye to have foveal vision in relative darkness. They were aware that the owl, which preys in the night, or the mole, which spends its life underground, were provided with rods even at the point of most distinct vision, and that there are night prowlers having only rods in the retina and no cones whatever. We are all color-blind when the intensity of illumination is too low to excite the cones. In Daltonism, or congential color-blindness, the cones do not functionate at all, the rods being the only elements which can be affected by any luminous intensity. König, Hering, Hillebrand and others, through extensive physiological research arrived at the conclusion that the visual mechanism is sensitive to gray and white, independent of color, while not going so far as to differentiate the functions of the rods and cones.

IV.

While the function of the visual rods is limited to the perception of form and of white or gray light, it devolves upon the cones to so modify the rays of radiant energy falling upon them,

that the resulting stimuli, passing to the cerebral centers, may create the sensation of colors.

Of the various theories advanced to elucidate the perception of color with its many modifications, that advanced by Young and later endorsed by Helmholtz and others, after an exhaustive series of experiments and observations, is most commonly given precedence. This theory is based upon the observation, that the exhaustion of the color perceiving elements of the retina is expressed in either red, green or violet, which colors are therefore designated as the primary retinal sensations for color, all color sensations other than these being composed by combinations in varying proportions of the primary color sensations.

This theory teaches that there are in the retina three classes of cones which respond respectively to rays of radiant energy having the rates of vibration corresponding to these primary colors, each cone responding only to the rate of vibrations to which it is, we may say "attuned," while the intermediate shades of color are produced by the stimulation of the three primary color terminals in varying degrees, the sensation of white being produced when the three elements are equally excited.

Thus if a large number of cones responding to the vibrations to the extreme left of the spectrum are brought under the influence of these rays, and those which respond to green and violet are hardly affected by their corresponding radiations, the sensation would be red. If, however, the cones responding to red are affected considerably less than those responding to green and violet only slightly, the color sensation would be that of orange.

Visual purple existing only in the rods, the supposition is tenable that other similar, though invisible, substances are formed in the cones, the decomposition of which produces the form and quantity of stimulus requisite to excite in the centers the sensation of color.

This supposition is not incompatible with the Young-Helmholtz theory of color vision if one supposes that there exist in the cones three substances, possibly of the character of ferments, capable of specially responding, respectively, to radiations having

the requisite rapidity of oscillation, or one substance only, having the property of three separate reactions in an ascending scale. Kries believed that all the cones are excited by light of all colors without exception. One group of observers advances the hypothesis that the retinal process by which radiant energy is converted into heat or electrical energy may be a process of fermentation and that the ions of luminiferous ether, acting upon the ions set free by the intra-cellular ferment substance, may produce within the protoplasmic cells thermo-chemical changes, thereby generating an electro-vital force, capable of nerve stimulation, which is conducted by the filaments of the optic nerve to the visual centers in the brain to be there interpreted as sensations of light and color.

Fotherby suggests that an ionic action is induced by these radiations in association with three distinct ferment substances present in the cones, specialized to receive them, each ferment being specially capable of producing katabolic changes under the influence of the particular radiation concerned; and from the energy thus liberated three corresponding degrees of nerve stimulation arise, which are interpreted by the consciousness as the primary color sensations, red, green and violet.

Hering, in his theory of color vision, advances the supposition that there are six primary color sensations, *viz;* three pairs of complementary colors, black and white, red and green and yellow and blue, and that these are produced by changes either of disintegration or assimilation taking place in certain intra-cellular substances, of the nature probably of visual purple, though invisible. He claims that each of the substances corresponding to a pair of colors, is capable of undergoing two changes, one of construction and one of disintegration, thus producing one or the other color sensation, which originate through changes in that particular substance.

These two theories, the Young-Helmholtz and Hering, may be called the classical theories of color vision, although the Young-Helmholtz theory appears to meet the requirements in many respects more adequately than that advanced by Hering. The greatest point of contention in the Young-Helmholtz theory has been that in cases of blindness to red, the individuals are still

able to perceive white, of which red is a constituent part. Another point of contention has been in the fact that all colors appear gray when the intensity is small and white when it is very intense. However, the experiments conducted by Drake and Weber, proving that the rods alone appreciate light which is innocent of spectral colors, or colorless, explain these points of contention: the color sense may be defective in the perception of one or more of the primary colors and yet the appreciation of uncolored light, by way of the rods, be unimpaired. One observer writes, years prior to the experiments of Drake and Weber, "There seems to be no reason why a color which acts chiefly on *one* form of cell, when of *moderate* intensity, should affect the three forms equally when faint or intense. This is one of a number of facts which make it necessary to assume that the visual mechanism is sensitive to gray and white independent of color."

The sensitiveness to colors differs widely in different individuals; the sensitiveness in a given case may be as much as ten times that in another, although the color vision in both may be regarded as normal. Such a difference usually passes unnoticed on the part of the ophthalmologist and the individual himself may be ignorant of the fact that his eyes are more sensitive to color than are those of his neighbor. Also, a given individual may be more sensitive to ordinary lights than another, yet without showing any pathological alteration or difference of ocular structures which might be detected by present methods.

Protoplasmic cells, of which the retinal rods and cones are types, are the basal units of all living organisms. Each cell is a living entity and functionates independently of its fellows. It has the power of breathing—the assimilation of oxygen; of nutrition—the building up from food materials; of excretion or the throwing off of waste materials; of forming certain substances called ferments, which under certain condtions and favorable environment, are capable of producing either katabolic (destructive) or anabolic (constructive) changes, without the structure of the cell itself being affected in any way. Whether or not visual purple is in the nature of a ferment we do not know, but we do know that it is a substance formed within the

rods by cellular action, that it is decomposed by light, and that the cell protoplasm has the inherent power which enables it to keep the cell "charged" with visual purple. After a night's rest the visual acuity becomes much clearer, owing to the stored potentiality of the cell, but as the day passes the acuteness gradually diminishes until, toward the close of the day an object, given the same intensity of illumination, appears only half as bright as in the morning. This is supposed to be owing to the fact that as the day passes the reserve supply of visual purple is exhausted and, as the inherent potentiality of the cell diminishes, the visual purple is produced less abundantly with a corresponding diminution in reaction to light. The same reasoning holds good as regards the essential intra-cellular substance or substances formed within the cones, which, while invisible, are believed to be closely akin to visual purple, and subject to the same limitations.

The most obvious physiological characteristic of protoplasmic cells, is their power of movement; they also have an internal circulation made visible by the streaming of minute, intra-cellular granules, are exceedingly sensitive to stimulation and show irritability by movement, or by contraction of mass, and an acceleration of the internal circulation.

The contraction of the cones and the movement of the pigment granules in the presence of light are merely evidences of stimulation, whether due to heat, resulting from absorption of radiant energy by the pigment layer, or to electric disturbance resulting from the decomposition of visual substances. Moderate heat acts as a stimulant to protoplasmic cells; the optimum temperature being from 37° to 38° C. Weak electrical currents also stimulate the movement, while strong currents cause the cells to become motionless.

The best proof of the direct local action of light is that images thrown upon the fundus, when well defined, leave well defined designs in the layer of purple rods which are known as optograms. After an exposure of a fresh eye from two to seven minutes according to the intensity of the light the retina is prepared before a sodium flame, laid over night in a four-per

cent. solution of alum, and shelled out over small, glazed, porcelain cups where they can be examined by day light.

In this paper, the object has been to describe as briefly as possible, the minute organisms concerned in vision, their relation to each other, and their respective functions in composite vision. The subject is one with which every illuminating engineer should familiarize himself, the eye constituting the final judge of his product.

Within the past few years ophthalmologists and illuminating engineers, generally, have realized more fully that many of the problems of artificial lighting may be solved most logically and satisfactorily by a united effort, the ophthalmologist being in position to better comprehend the needs and limitations of the delicate visual structures, while it devolves upon the illuminating engineer to evolve and perfect artificial lights which, while producing the requisite intensity of illumination, will not react injuriously upon the ocular tissues.

DISCUSSION.

Mr. H. Kirschberg: There are one or two interesting points which I would like to bring to your attention. One is, in regard to the variation of color of signals on a railroad and concerns the possibility of that variation being due to the absorption of the shorter wave-lengths in the atmosphere. I have had experience in that particular subject in railroading, and while it is true that a great deal of variation in color experienced by engineers is due to absorption of the shorter waves by the atmosphere, a contributing fault of prime importance is the lack of purity in the color of the glass which allows waves to pass through which really should not.

There is another reason for the color error, that is, the difference between the reflected and the transmitted light of a signal lens or roundel. Not only the light coming through the glass, but also the possibility of reflected light should be considered. The color of a headlight has very often been the cause of complementary colors being reflected by signal glass.

Now, in regard to the tests of color blindness, or color perception. There are a good many individuals whose education

in colors has not been complete enough to enable them to distinguish between colors by name? They possibly can match colors, but not in the finer shades. It is just a case of not knowing colors by name.

The eye is going to focus on whatever light is in the field of vision if it can be seen at all. It is well known that an oil lamp can be seen distinctly a mile ahead on the railroad and that is about as much of the track as can usually be seen in this part of the country. The oil lamp is a sufficient marker to enable a trespasser to see that a train is approaching. As far as the engineer is concerned, no matter how strong his headlight is, it isn't going to enable him with any surety to differentiate between something on the track and a shadow due to some other light in a house along the right-of-way. At night the engineer runs his engine with almost entire dependence on his signals and takes chances to a great extent on the condition of the track. The use of an arc head-light would therefore lend him much assistance in running safely, but might introduce other factors of a dangerous nature.

Dr. Heckel: The visual act, according to my way of thinking it out, resolves itself into three distinct processes. The first is a purely mechanical process, in which the eye makes an image of the object which is produced upon the fundus of the eye.

The second act is a purely chemical process, in which certain definite and certain indefinite chemical changes take place within the retina. The chemical changes which take place are capable of over stimulation. If the demand is greater than the supply, it results in a chemical exhaustion, and of course in a temporary blindness or scotoma. For instance, an over-exposure of the eye to the light of vast snow fields gives rise to temporary blindness, which is the result of a chemical exhaustion.

The matter of color perception is a very broad and interesting subject and requires a little more time for discussion than I care to give it to-night; but Dr. Turner has mentioned several points upon which I wish to comment very briefly. For instance, the matter of color perception at twilight: the practical nature of color perception depends upon the nature of the illumination under which colors are perceived. If the light itself does not contain elements of the color, it is impossible to perceive that

color. That is why at twilight, with a certain absorption of some of the natural spectrum of the sun, certain colors are not so clearly distinguished. We are perhaps all familiar with the effects of a monochromatic light. Throw a little common salt into an ordinary gas stove or gas grate; after turning off all other sources of illumination bring up some bright colored object, *e. g.* a piece of bright red material and note how absolutely the color disappears, due to the fact that there are no red rays in the yellow sodium flame. That is the reason why, sometimes signals are misread by railroad engineers, due to fog, smoke, etc., in which a certain amount of the color which is ordinarily in the natural spectrum has been absorbed and gives a false appearance to the colored lights. The intensity of the color enables one to distinguish it also. A person may be absolutely color blind, and yet be able to recognize red because he is familiar with the intensity. But, if he is subjected to a physiological test, or Holmgren test, and given various shades of red, various shades of blue, green, yellow, etc., which have been mixed up with a lot of dirty browns and grays, etc., he will invariably make mistakes in color differentiation. He need not be asked to name colors. He will pick up green, pink, brown, yellow, etc., and say they are all of the same color. Yet the same person would probably say "red" immediately, if an examiner picked up a red and asked him to name it. Obviously then the intensity of the light has a great deal to do with the color perception.

The matter of chemical exhaustion is beautifully illustrated with the experiment of the cross which Dr. Turner alluded to. The picture of a cross is thrown upon the screen and the vision concentrated upon it for some little time. After the gaze is then directed upon a blank wall, the image of the cross will persist. The explanation is simply this: the bright illumination of the image on the retina has temporarily exhausted those elements which are necessary for the transformation of light energy over an area equal to the image of the cross formed on the retina, while the rest of the retina remains quite active. The light which now falls over the general area of the fundus produces chemical changes and the transformation of light energy, except over that part of the retina exhausted by the image of the cross; there-

fore the image of the cross stands out as a negative image or a temporary scotoma.

The locomotive fireman, for instance, who stoops down to fire his engine and exposes his eyes to the intense red glare of the fire box, after a few minutes of coal shoveling has a temporary scotoma or blind spot, which of course recovers itself in a very short time.

I think if we bear in mind that the visual act consists of this triple process, and that the chief one is a chemical change, and try to regulate the light accordingly, we may obtain some practical results. The matter of illumination is to try to produce conditions similar to those we find in nature. The quality of the light is only essential, I think, so far as the purpose to which that light is to be put. For instance, the mercury-vapor lamp is used in some factories because they have use for only a certain kind of light. If one wishes to enjoy beautiful colors he must have a light capable of bringing out all these colors. It is a physical impossibility to do that unless the source of illumination contains these colors.

I presume that if the illuminating engineer had everything at his disposal there would be no trouble in producing the light they desire. Of course, everything hinges on economy after all; so that although it is possible to illuminate a room successfully by absolute indirect illumination a consideration of cost is quite essential.

Now as to artificial illumination—of course, you know as well as I do that a source of light was never made to be looked at. We see things by indirect illumination—we see things by reflected light, and not by the light itself. So, if we simply remember that a source of illumination is not made to be seen, but is something to see by, and place it in a position so it does not strike the eye, we accomplish a great deal. Architects used to construct buildings that looked nice from the outside, but paid very little attention to the inside. Then when it came to placing the gas jets or the electric light fixtures, they didn't plan things properly; they placed a sixteen candle-power light near a window to do service or act as a substitute for daylight. I have in mind the Hotel Schenley ball room; you will remember that it doesn't

make any difference in what part of that room you stand those miserable brackets or side lights strike the eye. I think, bearing in mind a few of these things, and copying nature a little, and bearing in mind that light is not something to look at, but something to see by, we will have done a great deal in working out illuminating problems.

The matter of color blindness has been mentioned. In testing for color blindness it takes considerable astuteness on the part of an examiner, to detect it. The method employed is not to name colors, but to simply match shades. The individual doesn't name a color. He may pick out a green skein or a brown one or something else, and he will say they are all the same color; but if you pick up different reds and ask what color, he will probably say red; he recognizes it by its intensity, because he has been accustomed to calling it red. I could teach the same man colors in a very short time, so that he might pass a test by simply naming them, but he would fall down completely when he had to match colors. Place a red piece of glass over a lamp which gives a fairly good light and the same man may quickly tell you it is red; but if one keeps testing him he will hesitate and become confused and will call red, green or green red. I examined a man like that recently whose position depended upon his color perception. He was very much put out when I told him he was absolutely color blind. Yet given a green skein he would say immediately it was green. But in the color test he failed. He might give the correct color 99 times out of 100, but on the 100th time he would fail. You can readily see what this 100th time might mean.

Dr. L. O. Grondahl: The fatigue of vision one experiences after having looked at a bright object for some time is proof, I believe that there are several different substances in the retina of the eye. After the eye is fatigued by looking at a bright red object for a while, if one looks at a white surface, he sees an image of the red object in green or blue. The white surface furnishes all the colors and the green or the blue predominate in the sensation because the green and blue sensitive constituents of the retina are fresh, while that which responds to red is fatigued.

I don't know that I can agree with Dr. Heckel in regard to the colors in the late evening. I believe it is true that at a low intensity of illumination, even if the light is white, you will see blue objects in their proper color later than you can see the red ones; so that the constituent that responds to blue is more sensitive to the lower illumination than that which responds to red. This is also borne out by the fact that in heterochromatic photometry, at high illuminations red lights get the advantage, while at low illuminations it turns to the blue.

I would like to ask a couple of questions in regard to the rods and the cones. I was under the impression that the rods were particularly sensitive to blue light—more so than the cones; that the rods are the parts of the eye that take care of the vision when the illumination is low. Am I correct in that?

I would like to know whether I understood properly in regard to the visual purple. Does it decompose, or does it simply migrate to another portion of the retina, as might be inferred from one of the illustrations.

I would like to know whether there is anything like fluorescence there that might explain the greater sensibility to blue than to red at low intensities. The greatest sensibility at ordinary intensities lies somewhere in the greenish yellow; at very low intensities, it is shifted quite considerably towards the blue.

In connection with the physical cause of the psychological effect which we know as light: I took part in some experiments two or three years ago at the University of Washington, where we tried to find out whether an electric current would produce the result that we get from looking at a bright object. The observer was situated in a very dark room with his eyes closed, and waited until his retina was well rested. Then a coil of wire, through which a heavy current could be made to pass, was placed down over his head to the level of his eyes. The current was turned on and off at irregular intervals without the observer's knowledge. It was the invariable experience of everybody that tried it to get a flash of light as the current went on or went off. We took this to mean that the induced current in the nerve fibers or parts of the retina produced the sensation of vision. Of course, in ordinary vision there is something intermediate

between the electric current and the light stimulus, and that is probably the thermo-chemical reaction which Dr. Turner mentioned. The experiment seems a pretty fair proof at any rate that an electric current can produce the same effect as is produced by light.

This paper impressed me as a very able presentation of a subject that is very interesting and valuable to illuminating engineers.

Dr. Hunter Turner (in reply): The retinal rods react only to light without color, the resulting stimulus being generated by thermo-chemical decomposition of the visual purple which is found only in the rods. They react to intensities of illumination much below that required to excite the cones and, as Dr. Grondahl has said, "take care of the vision when the illumination is low" as in twilight.

The fact that a greenish-blue color can be distinguished at a much lower intensity of illumination than can red, is due, not to the reaction of the visual purple in the rods, but to the fact that the invisible visual substances in the cones are very sensitive to rays of radiant energy having rates of vibration corresponding to green, to yellowish-green and bluish-green.

The visual purple does not migrate, but is confined to the outer segment of the rods. The pigment granules within the pigment cells, however, under the influence of light, are carried into the fine protoplasmic processes investing the outer segments of the visual cells which are thus received within the pigment layer.

The only evident retinal manifestations of the action of radiant energy as has been stated in my paper, are the bleaching of the visual purple and the contraction of the cones.

INDIRECT ILLUMINATION OF THE GENERAL OFFICES OF A LARGE COMPANY

BY T. H. ALDRICH AND J. P. MALIA.

Synopsis: This paper describes an indirect lighting installation in the general offices of a large company. Tests of direct, semi-indirect, and indirect systems were made before the type of equipment was selected. The given data of these tests, the authors contend, show (*a*) that general office work—book-keeping, writing, reading of files, etc.—can be accomplished with comparatively low intensities of the indirect illumination, owing to its diffuse and uniform character; (*b*) deterioration of light caused by the accumulation of dust on the lamps and reflectors was approximately 10 per cent. per month for each of the three systems tested—a point which, in the opinion of the authors, emphasizes the necessity of cleaning lighting units once a month; (*c*) the indirect units were cleaned in one-half the time required for cleaning either the direct or semi-indirect units tested; (*d*) that considerable expense may sometimes be saved in wiring certain interiors for indirect lighting, and desk lamps may be eliminated, if the plans here outlined are followed; (*e*) comparative efficiencies of the systems tested. Illumination readings taken in various parts of the building are given.

We have divided this subject into five parts:

I. Sets forth the reason for the installation of a lighting system different from the one which was previously in use.

II. Results of tests made during trial installations of the different lighting systems.

III. Recommendations made by the committee in charge of tests.

IV. Results of tests made in various parts of the offices, five months after installation was completed.

V. Some advantages of indirect illumination for general office use, and conclusions drawn from this installation, regarding certain features requisite for indirect lighting of offices.

GENERAL DESCRIPTION.

Armour and Company's general offices are located in one building at the Union Stock Yards, Chicago. The general management and operation of their vast business is directed from this building where some 1,200 employees are engaged at general office work. To provide the best possible lighting system for such a large force therefore is a matter of vital importance.

In line with the policy concerning the general welfare of their employees, Armour & Company built some five years ago probably one of the most up-to-date office buildings in the country, for their general offices.

In the erection of this building, neither time nor money was spared to provide offices which from a welfare and utilitarian standpoint could not be improved upon.

The building is of a reinforced concrete construction, and occupies some 22,750 sq. ft. of ground. It is five stories in height. The total floor area in use is 113,750 sq. ft.

The major portion of the building is laid out in large open areas, where the majority of the employees are located. Some twenty-eight private offices are provided for the officials, the legal, purchasing, and motive power departments, and for the heads of other departments.

Every known convenience required for the comfort and efficiency of the employees has been provided for in this building. The notable features are:

1. Building constructed of reinforced concrete, and is fire proof in every respect.

2. Large window area, in preference to wall surface, around body walls of building.

3. Large open areas, permitting of good ventilation and circulation of air.

4. Satisfactory heating and ventilating system; use of washed air, heated to the proper temperature; and provision for the discharge of air at same time.

5. Double windows, to keep all odors out of offices, operated only by the use of washed air furnished by a ventilating system.

6. Modern sanitary equipment and toilet facilities.

7. Filtered and refrigerated drinking water furnished by a circulatory system.

8. Telegraph department, telephone exchange, restaurant, barber shops, rest rooms, etc., with complete equipments.

9. All telephone, light wires, and buzzer calls, installed in steel conduits, with floor boxes for convenient access and alterations of either buzzer or lighting systems.

10. Interior decorations of walls, which make ideal conditions for both daylight and artificial lighting. The ceilings are a light cream, the walls a light buff, down to a dado line 7 ft. 9 in. above the floor, and from this line to the floor line the wall has a light green tint.

Both the ceiling and walls are painted surfaces. The paint used, had but little oil in suspension so as to provide a surface flat or matte in appearance. From a utilitarian standpoint, as well as a lighting standpoint such a surface is considered good practise for offices.

The painted walls and ceilings are easy to keep clean. The surfaces look like but are more sanitary than calcimine. The glossy surface frequently found in offices is missing here. The ceiling and wall tints are most satisfactory colors, both for daylight and artificial lighting. With daylight illumination, the offices have a bright and cheery appearance, and reflect the rays of light received from the outside to the best advantage. Green on the lower part of the walls is particularly good practise. A light green is particularly advisable for wall tints where there is a large window exposure to the north and east light. It is a well known fact that the strong rays of light existing at certain seasons of the year are very irritating and injurious to the human eye, if they are allowed to enter through a large window surface and strike the eye directly or indirectly from polished surfaces at certain angles. If light tinted walls extended down to the floor line, employees, when looking up from their work, would be confronted with a bright wall surface which would, to a certain extent, reflect too high an intensity of light and thus affect the visual acuity or seeing efficiency of their eyes. With light green walls, the strong daylight rays are absorbed, diffused and reduced in intensity, so that far more hygienic conditions are furnished the office worker. The same principle holds true with artificial illumination coming from overhead general illumination. From a utilitarian standpoint, it is self-apparent that a light green painted wall surface is easier to keep clean than one of a lighter color, when either a painted or calcimined finish is employed. Painted walls and ceilings, in preference to calcimined surfaces, are coming into use quite generally,

because they are conceded to be preferable from both a sanitary and a utilitarian standpoint.

11. The illumination from the time the building was built in 1908, to August 15, 1912, was supplied by glower lamps operated at 230 volts, alternating current. The outlets were uniformly placed, four to the bay, on approximately 8 ft. 6 in. by 9 ft. 6 in. centers, except in each of the twenty-eight private offices, where an additional outlet was placed in the center, making five outlets to the room. There were installed 1,100 outlets in all. The major portion of all the outlets had single glower lamps, consuming 176 watts each.

In the private offices, single and some 6-glower lamps were installed at the center outlet. In the cashier's department some 4 and 6-glower lamps were also in use along the counter. In various parts of the building and along the walls were installed some 4-glower lamps. There were also a number of 110-watt single-glower lamps in use. The single-glower lamps had 4-in. enclosing alabaster ball globes; the 4-glower and the 6-glower lamps had 9-in. ball globes. The system was laid out on what is commonly termed the distributed outlet system, that is, providing several outlets to the bay in preference to one, permitting the use of smaller sized light sources, so as to reduce the high surface brightness of the light source, and to obtain better diffusion as well.

The heights of the ceiling on the different floors are as follows: first 12 ft. 6 in., second 15 ft. 9 in., third 15 ft. 9 in., fourth 15 ft. 9 in., fifth 13 ft. 4 in.

The walls and ceilings of the buildings had not been washed or painted for two years, excepting all private offices which were repainted in September, 1912.

I. REASON FOR DECISION TO CHANGE LIGHTING SYSTEM PREVIOUSLY IN USE.

The reasons for changing the original system were:

1. Dissatisfaction among employees, as regards the intensity of light and glare, on books and paper surfaces. There was a lack of uniformity of illumination throughout the offices, even with the many outlets installed. (2) Inconvenience of frequent

outages, caused by the short average life of the glowers, which averaged 500 hours, and, therefore, necessitated carrying around high ladders during working hours to replace glowers. It was thought that a system more hygienic and generally effective, would prove satisfactory for the office employees. The system sought also had to be easier to maintain, and operate at a lower cost for both maintenance and energy consumption.

II. RESULTS OF TESTS MADE DURING TRIAL INSTALLATIONS.

The tungsten lamp was selected as the logical light source to be used, on account of its economy, color value, ruggedness and general characteristics. What type of fixture and reflector should be adopted was to be determined by trial installations, in various parts of the offices, which should be installed for a period sufficient to permit an intelligent and correct decision.

Thirty-six lighting units with reflectors were installed in accordance with the engineering advice given by the manufacturers who supplied the equipments.

The following four types of reflectors, using the same size lamp in each case and operating under equal conditions were installed for testing purposes in the general offices or open areas:

Fig. 1 shows an indirect lighting unit. The fixture consists of a split canopy, brass chain, socket, and a spun brass bowl, having a one-piece corrugated mirror reflector on the inside. The reflector was suspended 30 in. from the ceiling, or 13 ft. 3 in. from the floor.

Fig. 2 shows a direct lighting unit. The fixture, which was suspended similar to the indirect unit, consisted of a form H holder with a satin finished prismatic reflector. The reflector was 13 ft. 9 in. from floor, or 24 in. from ceiling.

Fig. 3 shows a semi-indirect lighting unit. This fixture was the same as the indirect unit, except that it had a special shell to fit over the socket, from which was suspended two arms supporting the inverted reflector. The reflector was of medium density opal ribbed class, had a 2¼ in. holder and was suspended 12 ft. 4 in. from floor, or 3 ft. 5 in. from the ceiling.

Fig. 4 shows a porcelain enameled steel reflector. The fixture

consisted of a 15 in. enameled steel reflector, which suspended 18 in. from ceiling in each case.

The following four different types of lighting units were tested out and installed in the private offices for trial.

Fig. 5 shows a 500-watt single-unit fixture, having a one-piece corrugated mirrored glass reflector, with proper holder and jumbo socket complete. This type of unit was finally adopted for the majority of the private offices, to be suspended 36 in. from the ceiling. The lamps are inverted in the fixtures.

Fig. 6 shows a 5-arm fixture with five one-piece corrugated mirrored glass reflectors, using one 100-watt lamp in each reflector. The sockets were on 36 in. centers, or spread. Suspension 36 in. to ceiling. Lamps inverted form.

A porcelain enameled steel reflector unit (similar to Fig. 4) designed for either 400-watt or 500-watt lamp. Fixture was suspended 18 in. from ceiling, the height as recommended for all sizes of this type of fixture. Diameter 21 in. Lamp hung pendant form.

Fig. 8 shows a 500-watt single unit fixture, having a one-piece corrugated mirrored glass reflector, with proper holder and jumbo socket complete. This unit was adopted for the official's private offices only. Suspension 36 in. Lamps inverted form.

The foregoing lighting units are fairly typical of the direct, semi-indirect, and indirect systems most commonly found in use to-day for general office work.

No desk lighting units are used in this building.

Trial installations were made in December, 1911 and January, 1912. The three different systems were kept in operation during six months ending July 1. It was then decided to recommend a system for adoption.

Various illuminometer readings were taken showing foot-candle intensities as found under the different lighting systems on test. A record was kept of said tests.

Two sets of instruments were used for all foot-candle readings; both sets were sent to the Armour Institute for calibration several times during the test period, so that no errors would appear.

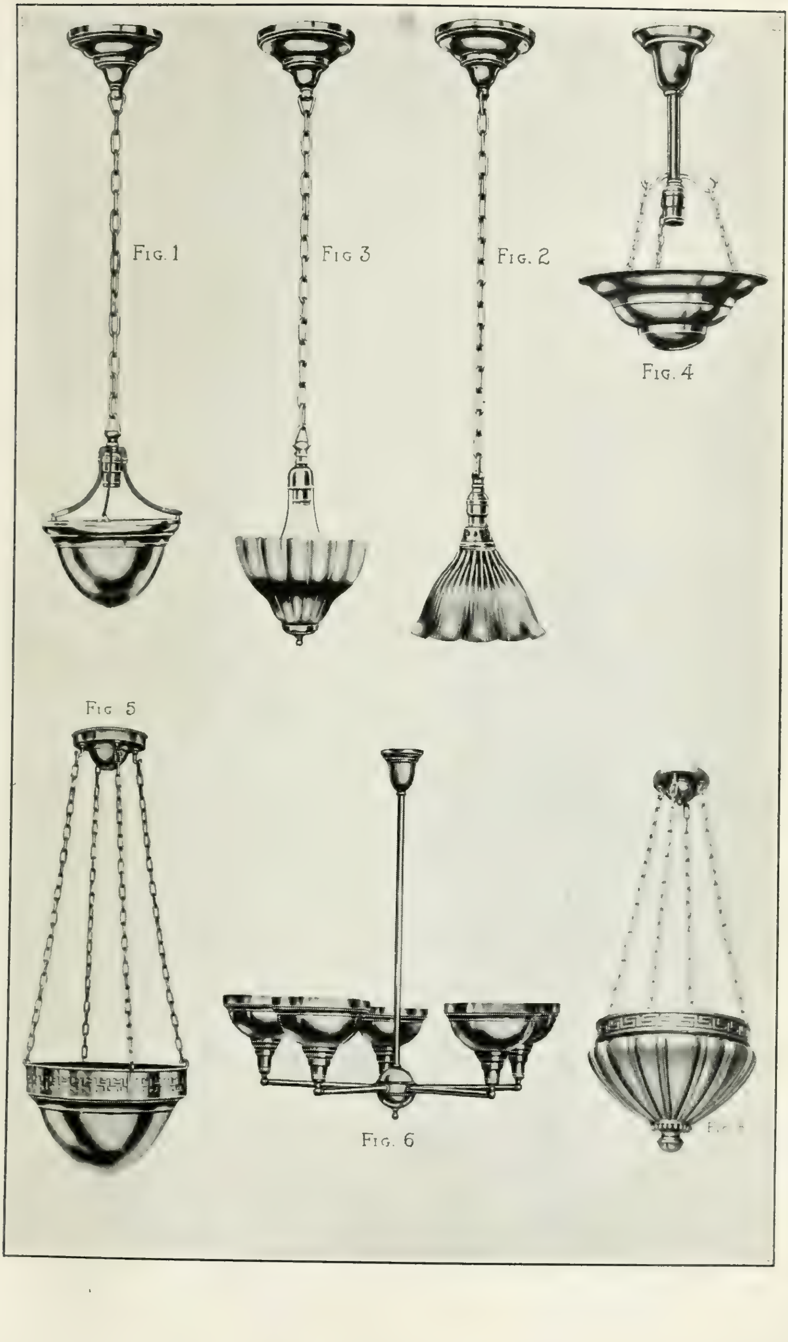


Fig. 1
Fig 3
Fig. 2
Fig. 4
Fig 5
Fig. 6

Fig. 11. (Top)—Open area on fourth floor.

Fig. 23a.—Drafting room.

Fig. 16.—A private office.

Twenty-five test stations were placed equidistantly apart in the center bays of the northeast and southeast wings. Readings

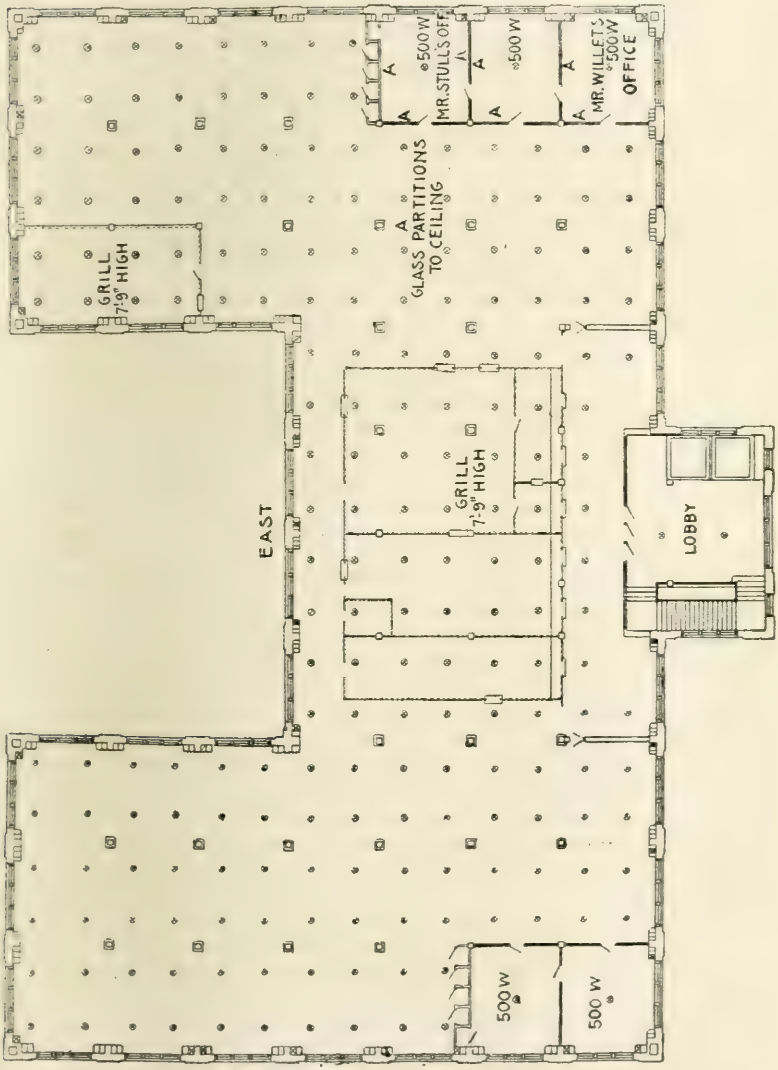


Fig. 10.—Typical floor plan of building.

were taken 34 in. above the floor. A portable photometer, millivoltmeter, and voltmeter were used for taking the necessary

readings. Voltage readings were taken at the panel buses some 50 ft. from the outlets tested. In the private offices, voltage readings were taken at the wall switch in each office.

All readings were carefully corrected according to formula used by the National Electric Lamp Association in rating the candle-power of all "National" tungsten lamps; and the average was taken therefrom in each case. All lamps were 112-114-116 volts, and were corrected to top voltage 116.

Illuminometer readings were also taken in the center bays of the northeast and southeast wings of the fourth floor.

Fig. 10 shows a typical floor plan of this building.

This plan shows the large open areas and the large window surface, which is advantageous for daylight illumination. The location of the outlets and character of bays are also indicated.

Preliminary Tests.—Five readings were taken in some eight private offices, average size 357 sq. ft. to determine the average foot-candle intensities obtained from the glower lighting in use. The average found was 3.24 foot-candles. The watts per room totaled 616, or 1.7 per sq. ft. Miscellaneous readings were also taken in various parts of the open areas, some stations beneath outlets and others midway between. Average found, 3.1 foot-candles. Watts per bay 704; watts per sq. ft. 2.1. Average size bay 320 sq. ft.

Test No. 1.—Indirect System.—Northeast wing fourth floor center bay; four outlets to each bay; all bays burning, using 36 indirect lighting fixtures as shown in Fig. 1. A 150-watt clear bulb tungsten lamp was used in all fixtures. Suspension 31 in. to ceiling, lamp hanging pendent, lamps all clean and new. Twenty-five test stations; average foot-candle 5.495. Efficiency 38 per cent. Same test made using 100-watt lamps in place of 150-watt lamps, lamps clean and new, showed an average foot-candle intensity of 3.76. Efficiency 38.9 per cent.

Test No. 2.—Direct System.—Northeast wing fourth floor, center bay; four outlets to each bay; all bays burning using 28 100-watt and 8 150-watt frosted bowl tungsten lamps. Direct lighting with satin finished prismatic glass reflectors. Suspension 13 ft. 9 in. from the floor or 24 in. from the ceiling. Lamps clean and pendent; they had been burning two weeks. Twenty-

five test stations; average foot-candles 5.34. Efficiency 55 per cent.

Test No. 3.—Semi-indirect System.—Southeast wing fourth floor, center bay; four outlets to the bay; all bays burning, using semi-indirect fixtures having 100-watt lamps enclosed with medium density opal ribbed glass reflectors inverted; suspension 12 ft. 4 in. from floor, or 3 ft. 5 in. from ceiling; average foot-candles 4.88. Efficiency 50.7 per cent. Lamps were clean and had been burning two weeks.

Test No. 4.—Indirect System.—An indirect unit consisting of 15 in. porcelain enameled steel reflector, suspended by rigid stem and casing; suspension 18 in.; one 100-watt clear bulb tungsten lamp; lamp hung pendent. Four outlets to the bay. Northeast wing of building. One bay only burning. Average foot-candles 1.43.

Test No. 5.—Indirect.—Same type fixture used in Test No. 4, only 21 in. in diameter, 18 in. suspension. Center outlet only, one 400-watt clear bulb tungsten lamp. One bay only burning. Average foot-candles intensity 1.30.

Test No. 6.—Indirect.—Same type of reflector as used in Test No. 5. Installed in private office, 18 ft. by 21 ft.—378 sq. ft. Center outlet only, containing one 500-watt clear bulb tungsten lamp, all other lamps out, average foot-candles 2.63.

Summing up these tests, the relative efficiencies of the direct, semi-indirect and indirect systems on these tests show, on a foot-candle basis only, the following results—all lamps and reflectors were new and clean:

System	Average foot-candles	Efficiency Per cent.
Direct	5.34	55.0
Semi-indirect	4.88	50.7
Indirect	3.76	38.0

Later on, toward the end of the test period, illuminometer readings were again taken to ascertain the deterioration of light caused by dust accumulating on the reflectors on test for a definite period of time. The following results were obtained.

Test No. 7.—Indirect System.—Readings beneath indirect units located in center bay of northeast wing of building; re-

flectors not cleaned for nine weeks; average foot-candles, 2.51. All reflectors and lamps were then cleaned, and readings again taken; average foot-candles found 3.35. Increase in intensity 0.84, or 25 per cent. loss of light in nine weeks by dirt accumulation. Average loss per month is 11 per cent. A 100-watt clear bulb lamp was used. Efficiency: dirty, 26 per cent.; clean 34 per cent.

Test No. 8.—Direct System.—Readings beneath direct units located in center bay of north wing of building; reflectors not cleaned in 12 weeks; average foot-candles found 3.95. All reflectors and lamps were cleaned. Readings again taken showed average foot-candles 4.95. Increase in foot-candles: 1, or a 25 per cent. loss of light in 12 weeks by dirt accumulation. Average loss per month is 8.5 per cent. A 100-watt frosted bowl lamp in use. Efficiency: dirty, 41 per cent.; clean 51 per cent.

Test No. 9.—Semi-Indirect System.—Readings beneath semi-indirect units, located in center bay of southeast wing of building. Reflectors not cleaned for two weeks. Average foot-candles found 4.64. All reflectors and lamps were cleaned and readings again taken. Average foot-candles found 4.88. Foot-candle increase 0.24, or 5 per cent. loss in light by dirt accumulation in two weeks. Average loss per month is 10 per cent. A 100-watt clear bulb lamp in use. Efficiency: dirty, 48.2 per cent.; clean 50.7 per cent.

These tests, Nos. 7, 8, 9, show a very uniform deterioration of illumination from the accumulation of dust on the direct, semi-indirect, or indirect lighting reflectors, when installed in office buildings. To the office manager they indicate the necessity of cleaning all reflectors and lamps at least once a month so that the efficiency of the lighting system in use may be maintained at all times. Many complaints made by employees may often be attributed to dirty lamps and reflectors, or to blackened lamps.

A record was kept of the time required to clean properly each reflector on trial. The comparative results are given below. The lamps cleaned were in the test bay of the open area shown in Fig. 13.

CLEANING.

Test No. 10—*Indirect System.*—(36) outlets, lamp and reflector wiped clean, dry cloth only; time, 2 men, 60 minutes; 120 minutes total. 120 ÷ 36 = 2.25 minutes per outlet.

Test No. 11—*Semi-Indirect System*—(36) outlets, lamp wiped dry, reflectors were necessarily removed and wiped clean, dry cloth only; time, 2 men 120 minutes, each, 240 minutes total. 240 ÷ 36 = 6.5 minutes per outlet.

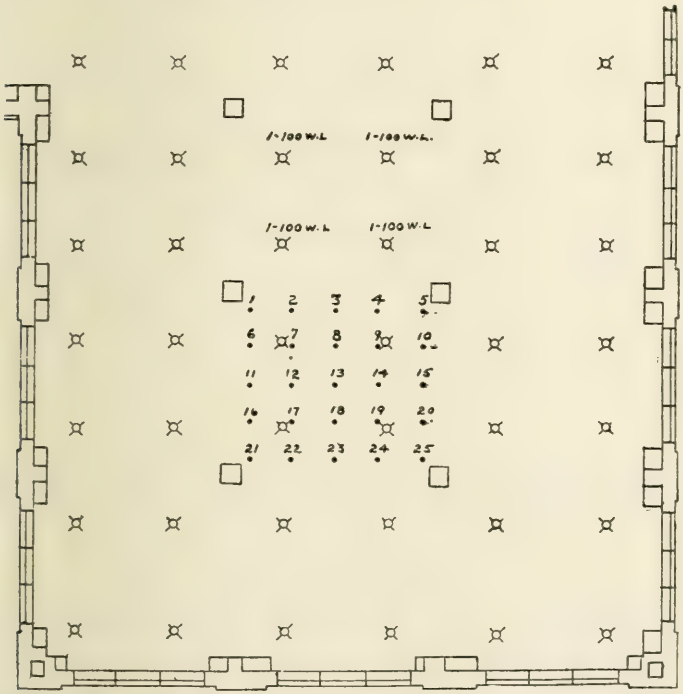


Fig. 13.—Plan of northeast wing of the building showing location of test stations.

Test No. 12—*Direct System*—(36) outlets, lamps wiped, dry clean cloth, reflector necessarily removed from form H holder, and was washed in water, and replaced in holder; time, 2 men 110 minutes each, or 220 minutes total. 220 ÷ 36 = 6 minutes per outlet.

Fig. 11 shows the interior view of the open area on the fourth floor of the building. Note location of outlets, post, beams,

windows and general office arrangement of desk, files, etc. Note the clearness of the posts and partitions some 150 ft. distant from the point at which the camera was located, also the absence of halation caused by the surface brightness or reflectors which is always in evidence in other systems than total indirect. Perfect uniformity and diffusion of light are the means of bringing out the interior arrangements to the best advantage.

Fig. 13 shows a plan of the northeast wing of building and the center bay where the test stations were located.

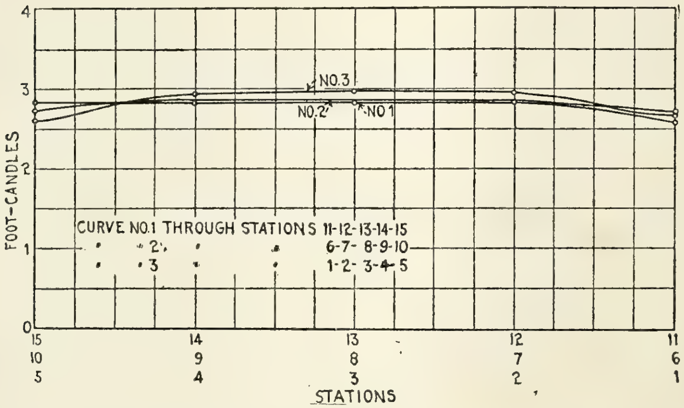


Fig. 14.—Curves indicating illumination in northwest wing of building; 4 100-watt indirect units suspended 26 inches from ceiling; all other bays burning; watts per square foot, 1.2; average foot-candles, 2.72; efficiency, 29 per cent.

Fig. 14 shows a uniformity curve, drawn through three rows of test stations located in center bay of northeast wing of building. Lights in all bays burning. 100-watt lamps in each outlet; suspension 26 in.; one-piece corrugated mirrored glass reflector. Lamps and reflectors not cleaned for 30 days. Note uniformity of illumination as furnished by this system, all lights burning.

Fig. 15 presents a uniformity curve showing efficiencies of one 400-watt lamp as compared with four 100-watt lamps at corners. Bay in open area, 4th floor; all other lamps out. Lamps and reflectors clean. Increase in foot-candles 0.16, by use of distributed outlet system; somewhat better uniformity also in evidence. The uniformity with the center outlet system, with all

bays burning, would probably be increased, as compared with only one bay burning.

Fig. 16 is a view of private office No. 1, size 18x21—378 sq. ft., ceiling 15 ft. 9 in., where tests were conducted, comparing foot-candle intensities, and uniformity of light as furnished by the center unit only, as compared with the four units at the corners of the ceiling. Same wattage each test.

Fig. 17 gives a plan of private office No. 1 showing test stations, where readings were taken.

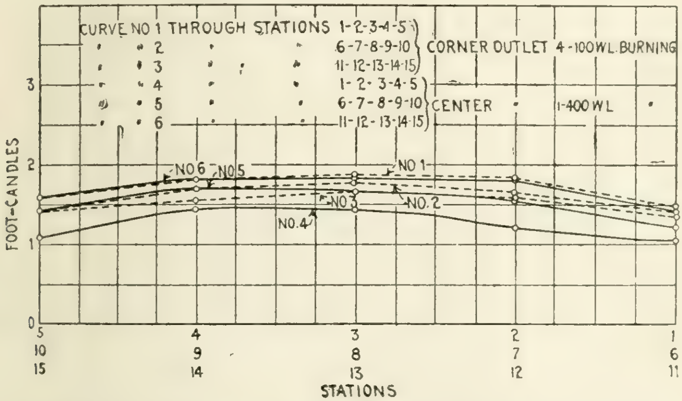


Fig. 15.—Distribution of illumination from one 400-watt center unit compared with illumination from 4 100-watt corner units. All other bays out. Average foot-candles from 4 100-watt units, 1.41; from 1 400-watt unit, 1.57.

Fig. 18 shows uniformity curve of illumination in this office; and also gives the average foot-candles with 1 400-watt clear bulb tungsten lamp located at center outlet, compared with 4 100-watt lamps at corners. Using the center unit only gave 1.26 foot-candles more than the illumination given by the 4 corners. The uniformity, however, was somewhat better with the 4 100-watt lamps.

Fig. 19 shows the plan of a private office similar to No. 1 (Fig. 17) and the location of test stations. Size of room 18x21—378 sq. ft.; ceiling 15 feet 9 inches; wattage 500; watts per sq. ft., 1.3.

Fig. 21 gives uniformity curves showing comparative efficiencies of 1 500-watt unit and a 5-arm fixture, 36 in. spread,

containing 5 100-watt lamps. Both fixtures 36 in. suspension. Both fixtures were equipped with similar reflectors. The

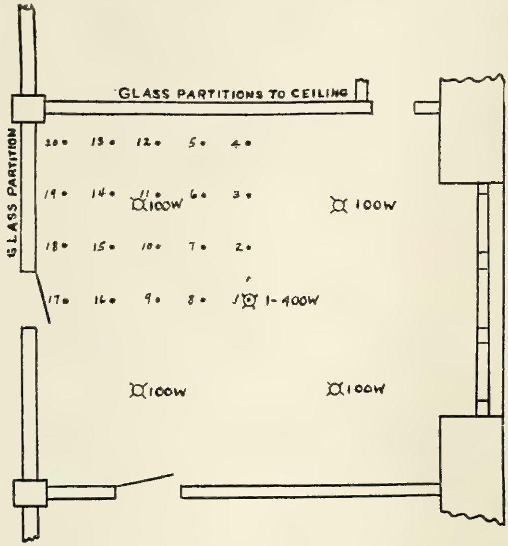


Fig. 17.—Floor plan of private office showing test stations, Area, 378 square feet; watts per square foot, 1.06.

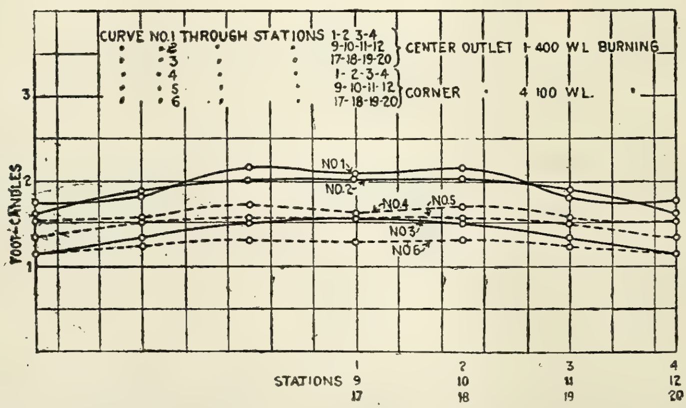


Fig. 18.—Illumination distribution, in a private office, from 4 100-watt units suspended 26 inches compared with illumination from 1 400-watt unit suspended 36 inches; watts per square foot, 1.47 and 1.75 respectively.

single unit gave 0.59 foot-candle more than the 5-arm unit. The 5-arm fixture gave more uniform illumination because it

lighted more uniformly a greater ceiling area, which fact was in evidence. Decrease in efficiency shown is attributed to the

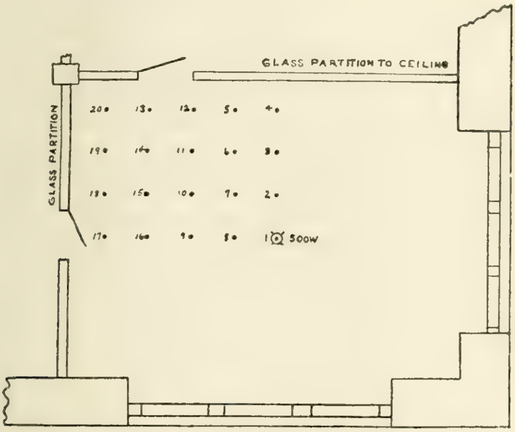


Fig. 19.—Floor plan of a private office.

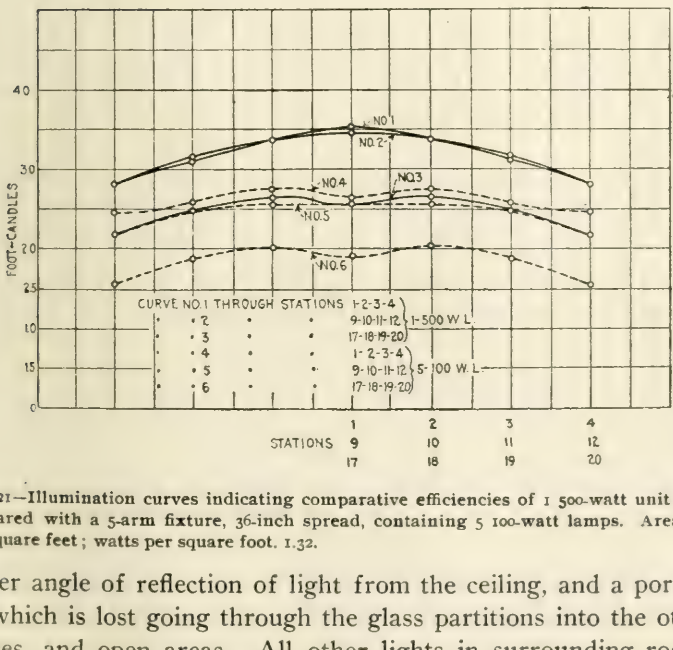


Fig. 21—Illumination curves indicating comparative efficiencies of 1 500-watt unit compared with a 5-arm fixture, 36-inch spread, containing 5 100-watt lamps. Area, 378 square feet; watts per square foot. 1.32.

wider angle of reflection of light from the ceiling, and a portion of which is lost going through the glass partitions into the other offices, and open areas. All other lights in surrounding rooms

were out. This comparison illustrates quite clearly that the main flux of light from an indirect unit can be controlled by reflecting to the ceiling at the proper angle the light directed from a properly designed reflector suspended at a correct distance from the ceiling.

Fig. 22 gives a diagram showing reflection of light rays from a ceiling; in one case a 1 500-watt unit is used; in the other 5 100-watt lamps in an arm fixture. It gives a graphic explanation for the lower efficiency of the arm fixture. Considerable light from the arm fixture passes into the next office. This loss would be reduced somewhat when all offices were lighted.

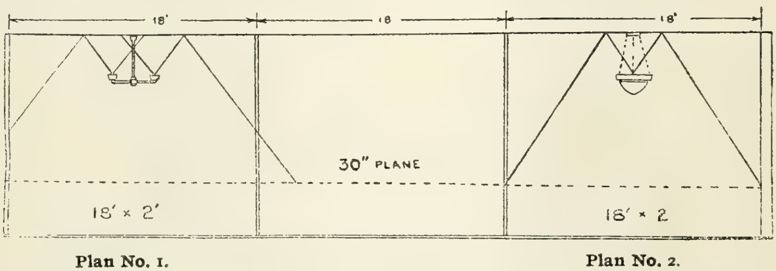


Fig. 22.—Plans showing two types of fixture in same office. Plan No. 1, 5 100-watt lamps, 36-inch spread; average foot-candles, 2.36. Plan No. 2, 1 500-watt unit; average foot-candles, 2.81. Suspension, 36 inches.

Fig. 23 presents uniformity curves showing the illumination in a private office with 1 500-watt lamp hung at 30 in. and 36 in. from the ceiling. An increase in efficiency with higher hanging height at the expense of the appearance of the fixture from an architectural and esthetic standpoint is indicated. For the latter reason, a 36-in. suspension was adopted.

Fig. 23a gives a view of a drafting room.

Fig. 24 indicates the locations of test stations in the drafting room.

Fig. 25 gives uniformity curves drawn through three rows of stations and shows the average intensity of illumination on the drafting tables. The readings were taken on a 42-in. plane. Average foot-candle 5.60. Size of room 36 ft.x58 ft.—2,088 sq. ft.; five 150-watt lamps to bay; ceiling 14 ft. 3 in.; watts per sq. ft., 2.

Fig. 26 is a view of the cashiers' department. The character of grill work is shown. In the last four outlets over counter at

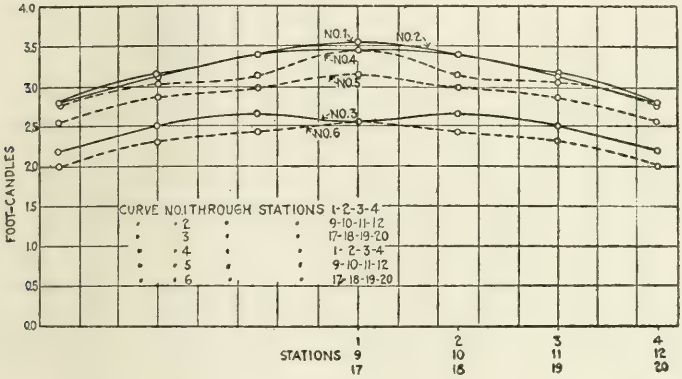


Fig. 23.—Variation in uniformity of illumination, private office, from 1 500-watt center unit suspended 30 and 36 inches respectively from the ceiling. Foot-candles, 30-inch suspension, 2.95; foot-candles, 36-inch suspension, 2.81. Area, 378 square feet. Watts per square foot, 1.3.

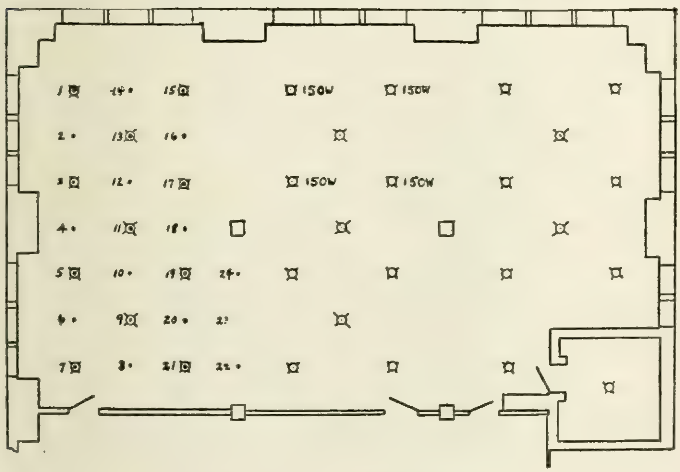


Fig. 24.—Plan of drafting room.

the left hand side of picture, six glower lamps were previously in use. In the four outlets at right hand side of picture, four glower lamps were originally used. All eight outlets at present

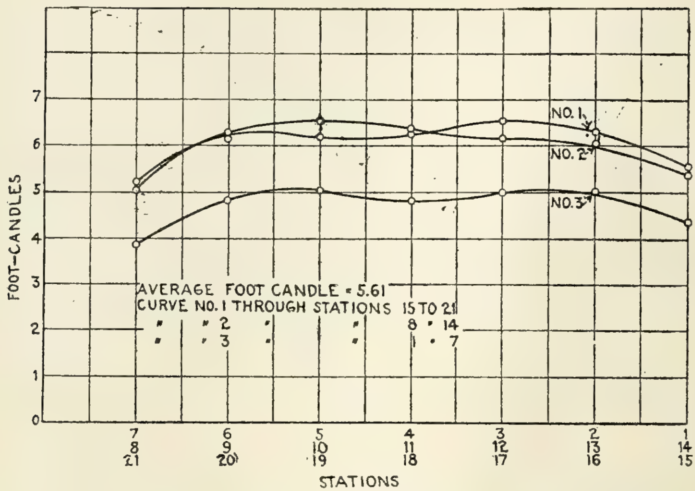


Fig. 25.—Distribution of illumination in drafting room. Average foot-candles, 5.61; watts per square foot, 2.00.

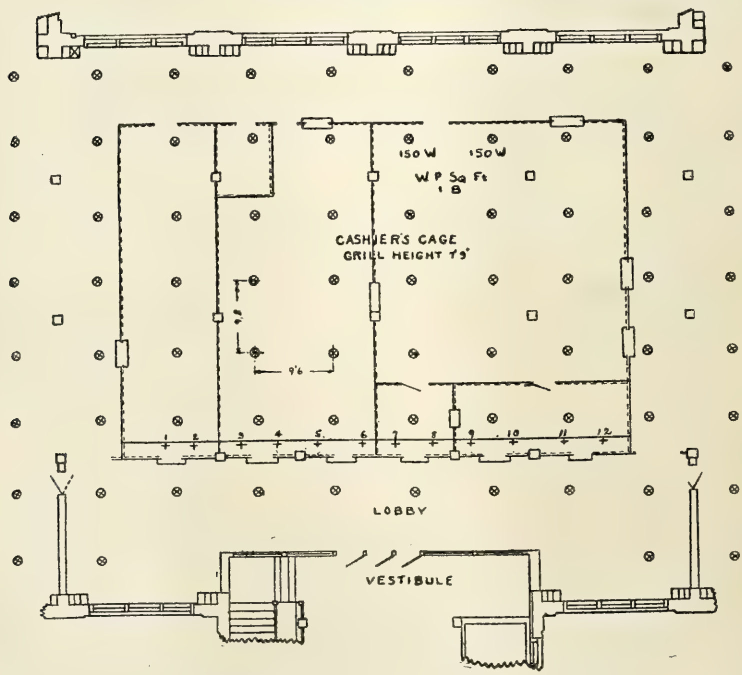


Fig. 27.—Plan cashiers' department.

Fig. 26.—Cashiers' department.

Fig. 33.—View of filing department on fourth floor.

Fig. 35.—View of construction department.

Fig. 37.—View of law library.

have 150-watt lamps each. The present illumination even though it is of a much lower intensity has proven satisfactory.

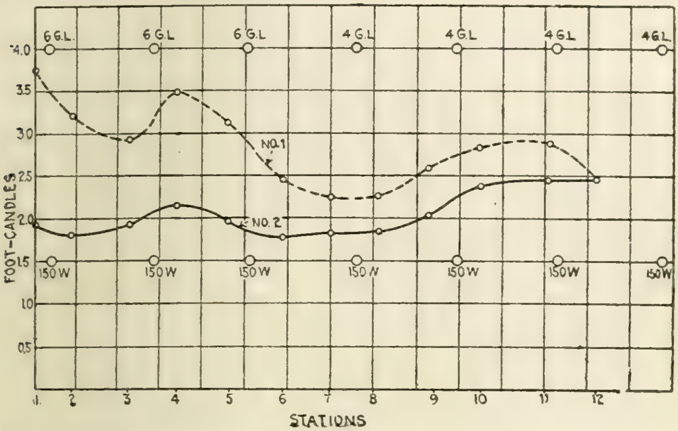


Fig. 28.—Distribution of illumination from old and new systems in cashiers' department.

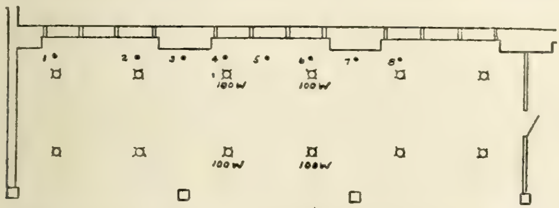


Fig. 29.—Plan showing test stations along west wall, north wing, on third floor.

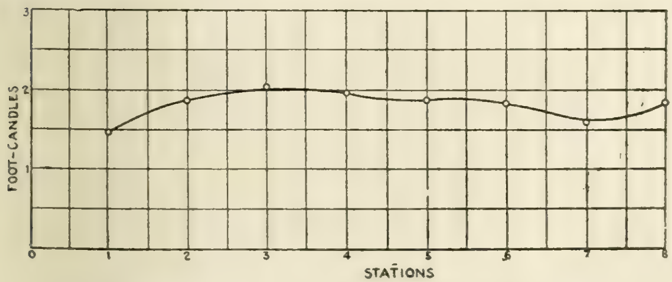
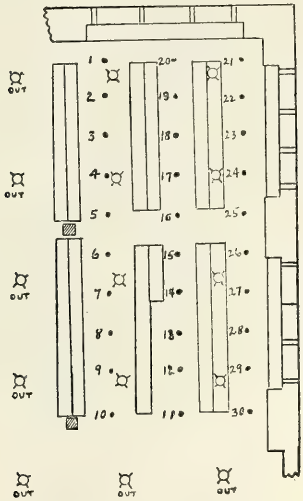


Fig. 30.—Distribution of illumination in area shown in Fig. 29.

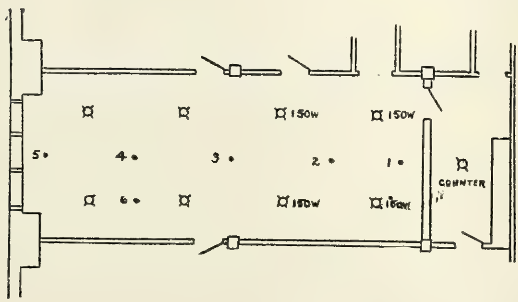
Fig. 27 shows a floor plan of working space in the cashiers' department and the test stations along the counter where illumination readings were taken.

Fig. 28 gives comparative illumination curves obtained from the original glower lamp lighting, and the indirect lighting now in use.



Station	Foot-candles
1	0.85
2	0.94
3	1.06
4	1.05
5	1.13
6	1.24
7	1.24
8	0.94
9	0.79
10	0.56
11	1.08
12	1.20
13	1.31
14	1.53
15	1.66
16	1.65
17	1.49
18	1.26
19	0.97
20	0.74
21	0.86
22	0.91
23	0.99
24	1.07
25	0.80
26	1.16
27	1.23
28	0.83
29	0.60
30	0.44

Fig. 34.—Floor of filing department, showing test stations and illumination readings.

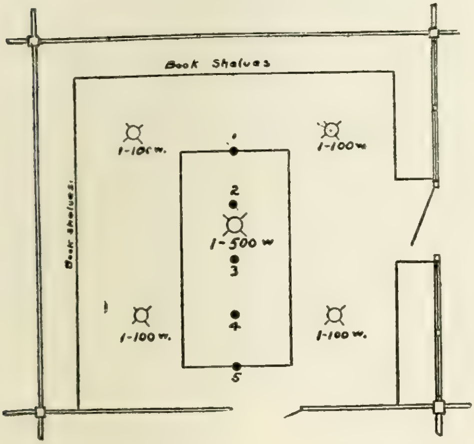


Station	Foot-candles
1	2.62
2	3.16
3	3.20
4	3.24
5	2.27
6	2.64

Fig. 36.—Plan of construction department.

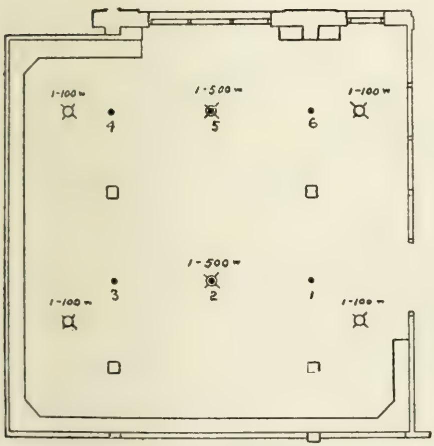
Fig. 29 gives the floor plan along a wall of the third floor; it shows the test stations, and location of outlets. Illumination readings were taken 4 ft. from body walls and on a 30 in. plane. All lights were burning. A 100-watt lamp was in each outlet. Flat stenographic desks were placed along this wall.

Fig. 30 shows the illumination through stations along body wall (Fig. 29) when all lamps were burning. The lamps had not been cleaned for 30 days.



Stations	Foot-candles
Center fiixture	
1	2.88
2	3.32
3	3.65
4	3.33
5	2.89
Watts per sq. ft., 1.6	
Corner fixtures	
1	1.71
2	1 87
3	1.90
4	1.90
5	1.62
Watts per sq. ft., 1.3	
All fixtures	
1	4.74
2	5.10
3	5.49
4	5.45
5	4.75
Watts per sq. ft., 2.9	

Fig. 38.



Stations	Foot-candles
1	2.31
2	4.06
3	2.28
4	2.46
5	4.18
6	2.82

Fig. 40.—Plan of girls' rest room.

Fig. 33 shows a view of the filing department, on the fourth floor, northeast wing.

Fig. 34 shows the floor plan of the filing department and

the test stations where readings were taken. The test plane was 30 in. above floor. A 100-watt lamp was in each outlet. Only the lights over files were burning when readings were taken. Note the very low instensities in the aisles between files. An illumination of 1 foot-candle has been found to be adequate. This illustration shows the advantages which can be obtained from uniform and diffuse reflection of light in any given area. The absence of shadows in these aisles also assist the eye in reading the filing matter.

Fig. 35 gives a view of the construction department.

Fig. 36 shows the floor plan of the construction department and the location of desks and stations where illumination readings were taken. This room is 16 ft. by 40 ft.—640 sq. ft. A 150-watt lamp is used in each outlet. Watts per sq. ft., 1.8. The lamps and reflectors had been cleaned before the test.

Fig. 37 presents a view of the law library.

Fig. 38 shows a floor plan of the law library and the location of test stations on the table in the center of the room. The foot-candle intensities indicated were obtained with only center units burning; with the four corner units only burning, and with all five units burning respectively.

Fig. 39 presents a view of the girls rest room.

Fig. 40 gives the floor plan of the girls' rest room and the arrangement of outlets and stations where readings were taken. This room is 39 ft. 6 in. by 39 ft. 6 in.—1,560 sq. ft. Watts per sq. ft., 0.9.

Fig. 44 indicates ceiling brightness with four corner units burning.

Fig. 45 indicates ceiling brightness with only center unit burning. The wattage of this unit was equal to the total wattage of the four units shown burning in Fig. 44. Note greater uniformity of ceiling brightness with single outlet system, also lower hanging height allowable, with center outlet. These two points are preferable from an architectural and esthetic standpoint, provided there is no appreciable decrease in the efficiency or uniformity of light furnished by this system.

Fig. 39.—Girls' rest room.

Fig. 46.—Employees' locker room.

Fig. 44.—Ceiling brightness with four corner units burning.

Fig. 45.—Ceiling brightness with only center unit burning.

Fig. 46 shows a view in the locker room for employees. Average foot-candles found in these aisles, 1.48. Each outlet has a 60-watt lamp. Area 40 ft. by 60 ft.—1,840 sq. ft. Total watts, 1,440; watts per sq. ft. 0.8; ceiling height 12 ft. 9 in.

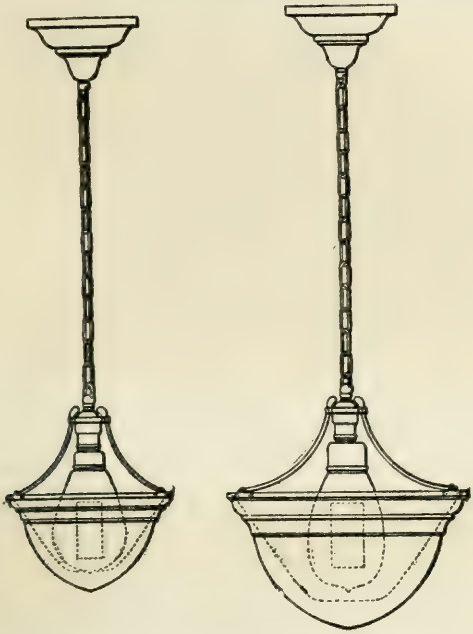


Fig. 49.—Plan of fixtures adopted for use in building.

Fig. 49 shows the type of fixture adopted for the building. Single 100, 150, and 250-watt lamps are used in the fixtures. A detachable arm permits quick cleaning of both lamp and reflector, without the removal of either.

III. RECOMMENDATIONS OF COMMITTEE IN CHARGE OF TESTS.

The committee in charge of the proposed change in the lighting system was composed of five employees of Armour & Company, namely, the general office manager, assistant to general office manager, superintendent of motive power, assistant superintendent motive power, and chief electrician. After thoroughly considering all the advantages and disad-

vantages of the three systems on trial, such as first cost, energy consumption, cost of up-keep, and character of light furnished, etc., and also noting the opinions of many employees working under the different systems, the committee decided unanimously that the indirect system would be the best system to adopt, both from a hygienic and an economic standpoint. A totally indirect system was installed August 1, 1912.

Such points as the comparative foot-candle efficiencies and energy consumed by the different systems were considered; and it was found that with the indirect system of illumination on trial a lower intensity of illumination was satisfactory for clerical work. This was attributed principally to the uniformity and diffuse character of the light so furnished by this system. Prominent shadows and glare from paper surfaces were also noticeably less prominent than with either of the other systems on test.

The estimated installation cost of the direct and semi-indirect on test was approximately the same. The indirect was estimated to cost somewhat more than either of the other two systems.

The estimated cost of operation including energy lamp renewals, and cleaning was in favor of the indirect system.

Careful record of the maintenance cost of the indirect system has been kept since the completion of the system, August 15, 1912, and it is interesting to know that for the first four months of operation of this system, ending December 15, 1912, the saving has been at the rate at which it was originally estimated per year. If the saving at this rate is continued, it is estimated that the installation cost will have been paid for in from four to five years, including interest on investment.

IV. SOME ADVANTAGES OF INDIRECT ILLUMINATION FOR GENERAL OFFICE USE, AND CONCLUSIONS DRAWN FROM THIS INSTALLATION.

From the various tests made and the uniformity curves plotted therefrom, it is quite apparent that uniformity and diffusion in artificial illumination can be obtained economically and satisfactorily by the indirect method. With uniformity and diffusion, the eye can operate with more freedom at lower inten-

sities of illumination. This installation shows upon reference to the various tests made under the indirect system, that very low intensities of illumination were found after several months continued use; but these proved adequate for office uses.

Considerable savings in wiring construction could undoubtedly be effected in such a building as here described. On account of the ceiling heights, this building could be lighted as economically and advantageously from a single unit in the center of each bay, either with one 400 or with one 500-watt lamp, as with four outlets to the bay. Offices of certain sizes having ceiling heights of from 13 ft. to 16 ft. can be lighted equally as well from one center outlet as from four outlets. The uniformity curves in this paper show this to be so. It therefore appears advisable to recommend a single center outlet in preference to four or more outlets for such offices. Considerable savings in both wiring and fixture installation cost may be effected.

From an esthetic and architectural standpoint the center bay fixture is preferable. It allows of a lower hanging height for the 400-watt fixture which has been described on a preceding page. It is also desirable from an architectural standpoint, when the ceilings are of the height mentioned. Ceilings from 13 ft. down to 8 ft. and with bays of such dimensions as are herein found should be lighted by the distributed outlet system in preference to a center outlet only. Another advantage is in the ceiling brightness; with only one unit, the ceiling presents a more uniform brightness; with the distributed outlet system there is a noticeable bright spot immediately above the fixture, and a dark area in the center between outlets.

Illumination by indirect methods permits of the extensive use of the larger tungsten lamps, such as the 400 and 500-watt size. A longer life and a comparative higher efficiency can be obtained by the use of these larger size lamps. The large lamps permit of quicker and more convenient cleaning, and with far less breakage, on account of their being far more rugged in construction. The adoption of large size units for use in either a direct or semi-indirect lighting system for bays as found in this building would be poor practise, because a high candle-power unit would be too near the working plane. The resulting glare and

the prominently defined shadows would make the lighting unsatisfactory for office work.

The indirect system used in the building was supplied by the National X-Ray Reflector Co., Chicago, Ill.

DISCUSSION.

MR. M. P. ROBINSON: Considering a number of bays in a building with four lights to a bay, uniformly distributed, as against the single light to a bay system, I am wondering if, when it is remembered that lamps are not replaced as punctually as they should be when their life's curve is running low, a more uniform intensity throughout the years of operation is not obtained with the distributed system than with the one light to a bay system. I should say that the small units in various places would keep the intensity in any one bay at a higher average.

It has been my experience in depending on one light to the bay, especially over an office which is rather densely occupied, that whenever there is trouble with one of the large units, many people are demoralized over, say, a period of 15 to 20 minutes, until the electrician can bring a stepladder and a new lamp and make the change; whereas in the case of four lights to the bay, if one light goes out, the persons in that bay do not have to discontinue work, because the other three lights will be sufficient until the defective one can be replaced.

MR. L. G. SHEPHERD: I would like to ask Mr. Aldrich a few questions relative to the cost of the various systems on trial.

First, since the first comparative figures as to efficiency seem to show the semi-indirect as a better proposition, than the indirect, was it not your cost of upkeep figures that turned the results to the favor of the indirect system? The figures given for the cost of cleaning the semi-indirect are considerably higher than those for cleaning the indirect system.

Second, if the cost for upkeep and the allowance for breakage were omitted, would not your tests have shown the semi-indirect to be a better proposition than the indirect system?

Third, if it were not for the high cost of cleaning and general maintenance of the semi-indirect system, in comparison with the indirect system, would Armour & Company, in your opinion, have decided in favor of the semi-indirect or direct system.

Mr. T. H. Aldrich: Answering Mr. Shepherd's questions in the order in which they were asked, I will say:

First; the difference in the cost of cleaning and renewing lamps only, was approximately a ratio of 3 to 1 in favor of indirect as compared with the semi-indirect system. The efficiencies referred to were, direct 55 per cent., semi-indirect 50 per cent., indirect 38 per cent., showing an increase of some 12 per cent. in favor of semi-indirect; this efficiency rating is on a foot-candle basis only, and is not the deciding factor always in adopting any proposed system of lighting for office use. The total cost of installation of the indirect system, which included cost of fixtures complete, lamps, and labor in installation, was, as stated, approximately 20 per cent. more than either the direct or semi-indirect system. The installation cost of the latter two systems was approximately the same.

Second; no, the installation cost of all three systems was a separate estimate entirely, from the estimated maintenance or upkeep cost of each proposed system. While the installation cost was 20 per cent. more than that of the semi-indirect, the maintenance including the cost of energy, cleaning, allowance for extra lamp breakage in cleaning, extra time necessary for cleaning on account of having four outlets to each of the 28 private offices, in place of one center outlet as adopted, would cost some 30 per cent. more than the indirect system proposed.

Third; In answer to this question I will say that I am not in a position to answer as to what decision Armour & Company would have come to, if the increased cost of cleaning, and lamp breakage, in the semi-indirect system were disregarded entirely. I know, however, that but little difference was apparent to their employees in the illumination furnished by either the direct or semi-indirect systems and that this point was considered before the indirect system was adopted.

Mr. J. R. Cravath: I think the real reasons for the popularity of the indirect lighting for general office lighting where it has been thoroughly and properly tried are the absence of sharp shadows and the reduction of glare from paper and desk surfaces. These two things are the most disturbing elements in connection with any system of lighting for general office purposes.

Even with indirect lighting as installed commercially, there are shadows and there is some glare from paper. We must therefore go further than the lighting system and attack the use of glazed papers and highly polished desk tops, if we are to get a complete cure for the trouble. The reason indirect lighting gives less glare from paper and less pronounced shadows than the other systems, is that the light is received from large surfaces. The more uniformly these surfaces are illuminated, the less trouble there will be from such glare and shadows. Of course, higher efficiency can be obtained by concentrating light on central ceiling areas and leaving the ceilings comparatively dark near the walls so as to keep light as much as possible from falling on the walls where it will be partly lost by absorption.

Although we should design for high measured illuminating efficiency wherever we can, we all recognize that high eye efficiency and human efficiency are still more important, and we should not hesitate to sacrifice some illuminating efficiency for the sake of obtaining light which is more comfortable and better for working purposes, where a large amount of work is being done. It will usually be easier to obtain approximate uniformity of brightness on the ceiling when four outlets are used per bay, than when one outlet is used. For these reasons, I think we should apply with a great deal of caution, the suggestions made in the paper of using one outlet per bay. With ceilings of the height here under consideration, namely 15 to 16 ft., it may be possible, by hanging the fixtures very low, to get a ceiling of sufficiently uniform brightness; but with lower ceilings, this would of course be impossible. To fully settle the question whether it is possible with 15 ft. ceilings to produce satisfactory illumination as regards sharp shadows and glare from paper, with one outlet per bay as against four outlets per bay, tests should be made with both types of installation. The quantity and character of the illumination received for working along and near the walls and windows should be considered.

Dr. M. G. Lloyd: One reason given by the authors for prefering a single central unit to the four distributed units in private offices is that a greater portion of the light in the latter case passes through the glass partitions and is lost so far as

usefulness in the room is concerned. I understand that the tests which warrant this conclusion were taken with the private office lighted and with the general office outside not lighted. If both offices are used at the same time this condition would not represent the usual working condition. With the outer room illuminated by a lamp similarly placed, there would be light passing through the partition in the opposite direction. This condition would correspond more nearly to that of a single room with light-colored walls in place of the glass partition; and the conclusions drawn by the authors would consequently not be so applicable.

In the diagram explaining this action, the authors indicate that the effect was due to the angle at which the light was incident upon the ceiling and the resulting path of the reflected ray intercepting the wall at points above or below the line separating the glass partition from the opaque lower portion. This explanation seems likely to give a wrong impression of the physical conditions. To me, the important point seems to be that in one case the ceiling near the center of the room receives the greatest illumination, while in the other the ceiling is brightly illuminated near the borders of the room.

If the ceilings have an approximately matte surface, as stated in the paper, the specular reflection represented in the diagram would be an insignificant portion of the whole and the observed effect would be due to the relative proximity of the brightly illuminated portions of the ceiling to the bounding partition.

In the tables applying to the law library, values of observed illumination were given for a single unit, for the four distributing units, and for a combination of both. I was interested to note that while the figures for the latter case were approximately equal to the sum of those of the other two cases, it was far from being exactly so. In other words, an additive relation for the light from the two sources does not seem to exist. It would be interesting to know the cause of this. Is it due to some physiological condition, or is the difference to be taken merely as a criterion of the accuracy of the observations?

Mr. F. A. Vaughn: I am a little in doubt as to the interpretation of the reference by the authors to the hygienic ad-

vantage of painted walls and ceilings over calcimined. I presume, however, that it is not intended to infer that there is any difference between the healthfulness of the two materials, as materials, but merely that the calcimine may become more soiled, or absorb unsanitary and uncleanly matter.

I presume, however, that a painted surface which is equally matte, that is, which has little enough oil in its composition to leave the surface equally flat, would be equally unsanitary from this standpoint. Therefore, for equal advantage from the standpoint of diffusion from the surface, the two types of finish, it seems, would be equally unsanitary.

There is an inference in the paper that "light green" walls are particularly efficient from the ocular standpoint, for use in installations of this character; but, although I have interested myself materially in the subject of relative advantages and disadvantages of various shades and colors of reflecting surfaces, I have not been able to obtain any direct evidence on the desirability of one shade or other over another. Therefore, while there is a more or less established idea that darker walls are beneficial from the standpoint of lack of glare within the range of vision, and while it is self-evident that the darker shades are more easily kept presentable, I would rather question the establishment of the idea that any one hue is better than another.

In connection with the authors' assumption from the experimental performance in an office having many windows and glass sides that, on account of the loss of light through windows into the adjoining areas, it would be better to always install one unit instead of many—it is felt that a word of caution should be given so that this assumption is not interpreted to include the illumination of large office spaces or the illumination of smaller office spaces where the walls are available for the confinement and reflection of the illumination lost in the case mentioned.

In other words, it is not believed that the authors can logically recommend the one-unit-per-bay type of illumination on the evidence secured by these experiments alone. It is, of course, apparently immaterial which type of illumination is employed if the ceiling could be, by either type, very uniformly illuminated.

It is, therefore, a matter of reflector design and choice, as

well as the choice of the number of units, which has a great bearing on this question as far as ocular efficiency is concerned; that is, the results on the illuminating plane, relative to diffusion and elimination of objectionable shadows, is dependent particularly on the degree of uniformity of the illumination of the ceiling, which in turn might just as easily be obtained from the distributed unit scheme as from the single unit scheme, if proper consideration were given to the choice of the units and their height of suspension.

Moreover, the illumination which spreads to the floor space exterior to the bay under consideration, is reciprocally returned in an open space installation by the units in the adjacent bay. It is consequently not logical to assume from the example given that the single unit type of installation is universally applicable to the best advantage.

I would also call attention to the nature of an assumption by the authors, that the light is directed in an indirect installation in a manner exactly the same as by specular reflection. This assumption is indicated by the diagrams. The diffusion characteristic of the surface of the ceiling would make this assumption at least doubtful.

Regarding the utility of the indirect system in connection with the operation of card files and vertical surfaces, I would say that this has been quite forcibly brought to my attention by some experiments performed preliminary to the illumination of the Milwaukee Public Library, where it was discovered that the index cards in the files of the catalogue room could easily be read with a surprisingly small amount of illumination from the indirect system. A very small fraction of a foot-candle of vertical illumination was sufficient to operate the files comfortably. This condition was very largely due, probably, to the diffusive character of the illumination and the fact that no objectionable shadows from the hands or body of the operator were encountered.

MR. T. H. ALDRICH: Relative to Mr. Cravath's suggestions as regards the desirability of obtaining perfect uniformity and diffusion by a multiplicity of outlets in preference to a smaller number, I might say that I believe such undoubtedly to be de-

sirable with ceilings from 13 or 14 ft. down to 8 ft. in height; but with ceilings and bays such as found in this installation, I think that with the center outlet only, there will still be in evidence a very much increased uniformity and diffusion of illumination, as compared with other systems. Mr. Malia and myself did not have the time available, nor the facilities, for temporarily installing some (36) center units only, in order to determine more positively the increase in uniformity which might be obtained with the four outlets instead of one, as Mr. Cravath has suggested. By referring to Figs. 44-45 it will be seen that a better ceiling effect is noticeable with the single outlet only, as against the four outlets. The ceilings in this installation also show a greater comparison than the pictures illustrate, as considerable clearness and detail has been lost in reproducing the photographs for printing.

Referring to Dr. Lloyd's contention regarding testing the illumination in the private offices: if the lights had all been burning in the surrounding area, the comparison of the light furnished by the single 500-watt unit with that supplied by a 5-arm fixture containing 5 100-watt lamps would not have been so noticeable. And the difference in the average foot-candles found would have been reduced somewhat, if all lights had been burning; but there would always be present the loss caused by the absorption of the clear glass which could not be eliminated. If these glass partitions had been plastered, and tinted in some light or medium toned color, I believe that a higher average efficiency would be obtained by the use of a single unit fixture, for the light rays would strike the ceiling at a shorter angle from the nadir, and the main flux would therefore be reflected more properly into the room where it was required. I think each room or bay in any open area should be considered as a complete lighting problem by itself. Of course in such cases, one would expect that when the system for the whole area was installed that with all lights on much better uniformity and diffusion and higher illumination efficiencies would be in evidence.

Referring to the different points raised by Mr. Vaughn, I should like to say, first, pertaining to the hygienic value of painted walls compared with calcimined walls for offices, that

my deductions are based on seven years service in general office up-keep and management. Walls and ceilings which have been properly primed, after being thoroughly dried out and which have had two coats of paint applied evenly over the entire surface, will be preferable from an up-keep standpoint, because they may be cleaned easily. Such paints as here referred to should not have over 25 per cent. of oil. If a larger amount of oil than 25 per cent. is added to the pigment, gloss will appear when paint dries, a condition which is generally conceded to be objectionable. Wall surfaces, particularly from a 5 to 7 ft. dado line down to the floor should be painted surfaces of medium tone color preferably of the darker shades which are more practicable.

From a sanitary standpoint a well painted surface is preferable to a calcimined surface, because the calcimine turns a much darker color and gives off a musty odor when moisture is in evidence. The odor comes from the glue and other ingredients which are found in all calcimines. Moisture is quite frequently present in offices at certain seasons of the year, especially during the summer season, and also when a building is near large bodies of water. I have noticed this physical change quite often in connection with the up-keep of a large office building situated near to the lake in Chicago. This unsanitary condition of the calcimined surfaces can also be caused by a high humidity which is sometimes found in offices where the ventilation is furnished by a washed air system. If painted surfaces were in use instead of calcimine, the moisture would have no effect upon the ceiling or wall surfaces. Regarding the matte appearance of both surfaces, there is practically no difference between them. The suggestion in the paper of the advisability of a light green tint, in preference to some of the other colors for wall surfaces is made with the knowledge that the green background as found in nature in the summer is most comfortable for the eye to rest upon. From experience I am also led to believe that this same effect upon the eye can be produced by the use of greenish tints for walls under artificial illumination. I am not sure but that there is some physiological reason for this. Relative to the shade of color for the walls,

I think that the lighter tints when they are within the line of vision are not conducive to ocular comfort. And when very dark tints are in evidence, there will be too much contrast effect for one looking up from white paper surfaces.

I think that the inference relative to the single outlet was misconstrued by both Mr. Cravath and Mr. Vaughn. It was our intention to say that, where ceilings of the heights herein mentioned together with bays and private offices of the given sizes are found in practice, there is but little increase in the uniformity and diffusion of light in favor of the distributed outlet system. If this is so why not save some of the initial costs of installation and provide better appearing ceiling brightness and a system which on account of the fewer fixtures required would be more satisfactory from both an architectural and an esthetic standpoint.

The assumption which we made in drawing Fig. 22 which shows our theoretical deductions as to the reflection of the light rays from the ceiling is in accordance with the law of reflection. We were aware of the fact that, if the ceiling were a highly polished surface, a greater proportion of the incident rays would be reflected at the same angle from the ceiling surface. On account of the ceiling being a smooth plastered surface with a semi-flat painted finish, a large proportion of the incident rays are refracted and diffused; so that the angle of reflection is somewhat altered. The main flux is not reflected with the same degree of uniformity, in accordance with the laws of reflection, as when highly polished reflecting surfaces are found. If the light rays from the reflectors used in the 5-arm fixture, when striking the ceiling, were refracted to the extent of causing diffuse reflection immediately above the light sources, and if such performance were to take place, instead of the rays acting in accordance with the laws of reflection, it would then seem logical that at least an equal average intensity of illumination would be effected. The tests, however, do not show this to be the case.

In concluding the discussion, I might say that both Mr. Malia and myself have endeavored, in presenting this paper, to show principally the practical application of a complete system of indirect illumination, as applied to general office uses. We de-

sired to be able to present a more comprehensive paper, taking into consideration more of the unknown engineering features of this system of illumination, but the necessary time was not at our disposal.

An economical and satisfactory indirect lighting system planned for office use, should have the following characteristics, and fulfill the following requirements:

(1) The proper location of outlets, by which the greatest possible diffusion of light is obtained. (2) The proper type of reflector, and the suspension height, which produces a ceiling brightness of good uniformity, desirable from an esthetic as well as an engineering standpoint. (3) The adoption of the most efficient reflector obtainable, designed to control and direct the rays of light toward the ceiling, at the proper angle, so that, in turn, the main flux of light striking the ceiling will be reflected down on the working plane, within a given area, as may be required. Mere ceiling brightness does not furnish economical or satisfactory lighting conditions. (4) The adoption of a reflector having a reflecting surface with a high co-efficient of reflection, and permanent in nature, on account of which quick and convenient cleaning and maintenance can be accomplished. (5) The adoption of fixture equipment, containing the necessary reflectors, special consideration being given to its utilitarian and its architectural value. (6) The adoption of a methodical system of up-keep, such as the cleaning of all lamps and reflectors at least once a month, or more frequently if conditions warrant, in order that the lighting system may be kept up to its initial efficiency. If the efficiency and the continued welfare of the employees are considered of prime importance, the method of cleaning of any lighting system must be carried on in a systematic manner. Many complaints are attributable to dirty illumination equipment and blackened lamps.

THE EVOLUTION OF THE LAMP.*

BY ROSCOE SCOTT.

Synopsis: The following paper outlines the evolution of several illuminants—the candle, oil, gas and electric lamps—beginning with their primitive forms. A bibliography on the subject is appended.

INTRODUCTION.

The study of an evolution, whether it concern a living organism, such as man, or a manufactured product, such as the lamp, consists largely in reviewing a mass of prehistorical data. Accordingly persons of that pre-eminently practical mentality that distinguishes our hustling twentieth century, often profess indifference when evolution comes up for discussion, even when it relates to those objects in which they are naturally supposed to be vitally interested. Mr. Edison, for example, when interviewed some time ago by the writer, remarked "I don't like to go into things connected with ancient history, or the dead past,—what I am interested in is the future: in what is going to happen tomorrow." Yet even Mr. Edison has always made it a point to be familiar with the previous development of any product which he set out to improve.

But the evolution of the lamp is of more than academic interest, and its principal facts should form part of the illuminating engineer's education. Such a study discloses what types of men and circumstances have produced the greatest improvements in lamps and illumination methods, and leads one to predict that similar combinations of men and circumstances will produce important results in the future. Upon noting the cardinal dates in lamp history, and incidentally their increasing frequency in recent years, one may venture to extrapolate the "curve of progress" and form some idea of the extent to which lamps may be improved in the next generation. One may look forward to a day when, due to constant diminution of the cost and increasing of the standard of illumination, the world's total installation of lamps

* A paper read at the seventh annual convention of the Illuminating Engineering Society, Pittsburgh, Pa., Sept. 21-26, 1913.

of all kinds will be 40 or 50 candle-power per inhabitant, although at present there are tribes, in Polynesia for example, that are known to have no lamps whatsoever,—that are at the same stage of development, from a lamp standpoint, that all mankind was, ten thousand years ago.

Lest anyone should carp at the phrase "evolution of the lamp," in the title of this paper, it may be well to mention that, except in a general sense as I am using it, to include lamps collectively, there is no "*the* lamp." Some persons may be so biased as to think that there will eventually be a "the lamp,"—a type or class of lamp in universal use,—but a study of the subject from the evolutionary standpoint leads to the opposite conclusion, namely, that we are getting farther and farther away from "the lamp." The ancients knew but one or two general types of lamp, while to-day there are many, and, for reasons too numerous to mention, many are required. It would seem about as logical to assert that, since the highest development in the animal kingdom is *genus homo,* therefore *genus homo* must, forsooth, supersede all other forms of animal life, as to predicate that simply because this or that lamp represents the highest point reached in modern lamp development, it will drive all others from the face of the earth. No evidence exists in support of either contention. On the other hand, it must be admitted that there may very easily be a lamp so far superior to others for general purposes that it may be recognized as the highest development in the field.

The analogy between the evolution of the lamp and that of living organisms is strikingly brought out by the following quotation from an authority on the last mentioned subject:

> In general, the progress of evolution has been from the simpler toward the more highly organized and specialized types, though many examples of retrograde evolution or reversion to a simpler type occur.
>
> The various living and extinct types do not form a simple series, but a genealogical tree whose branches exhibit very different degrees of divergence from the parent stock. Many branches have died out completely, and are known only by fossils.*

To relate, in detail, the evolution of the oil lamp, or of the inverted mantle gas lamp, or of the tungsten filament lamp, would

[1] See definition of evolution, Webster's Unabridged Dictionary.

require a paper many times the length of this one. Evidently, then, I can attempt only to trace broadly the unfolding of the major groups, and a few of the more important sub-groups, into which illuminants naturally divide themselves.

A bibliography is appended to the printed edition of the paper, for the benefit of any who may wish to investigate, in some leisure season, the lamps that lighted the paths of our forefathers.

Taking the barbarian camp-fire as probably the earliest form of artificial illuminant, or lamp in its broadest sense, in the following paragraphs will be discussed successively the evolution of lighting arrangements employing solid, liquid, and gaseous fuels and lastly those energized by electricity.

FIREFLY LAMP.

Just in passing, I may mention a curious primitive lamp or lantern, which falls under no ordinary classification. It can hardly be called an artificial illuminant; perhaps it might best be called an artificial collection of natural illuminants. I refer to the West Indian firefly-box shown in Fig. 1. Many travelers have recorded the use of fireflies as lamps by natives of the tropics. The box here illustrated is on exhibition in the New National Museum, Washington, D. C., and forms part of an extensive and highly instructive collection of fire-kindling and light-producing devices brought together largely through the efforts of Dr. Walter Hough.

SOLID FUELS USED AS LAMPS.

The pine knot blazing in the camp-fire, or the fire-brand, snatched from the latter for light and protection during the savage's nocturnal excursions, served the purpose of lamps until, as dwellings grew larger and men—or more likely women—came to appreciate the virtue of cleanliness in housekeeping, it was found desirable to provide a special holder for the burning wood. Fig. 3.

It may be presumed that the making of special holders for splint-lights dates back to the earliest times when men first learned to fashion rude household implements of stone. Homer mentions "metal braziers filled with blazing pine knots," and refers to the torch as the ordinary means for lighting dwellings.

Fig. 1.

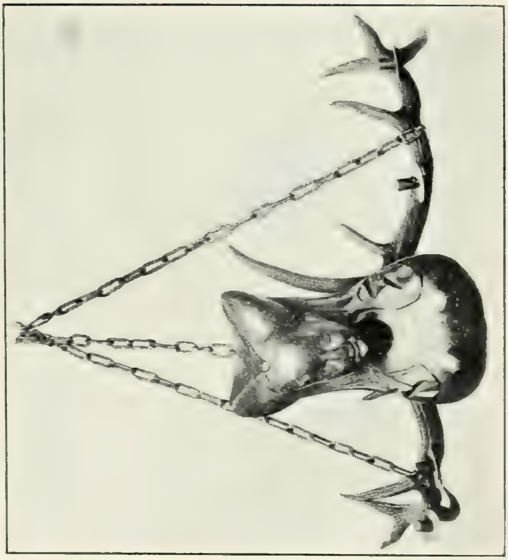


Fig. 19.

Fig. 3.

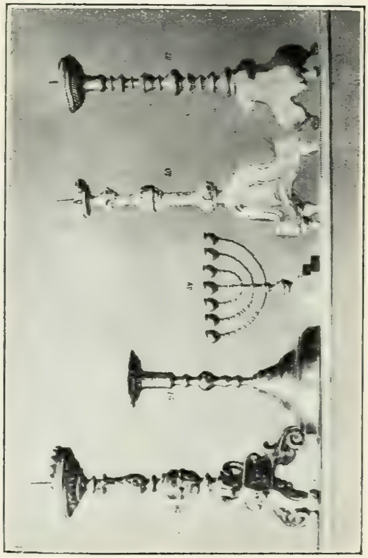


Fig. 20.

Fig. 21.

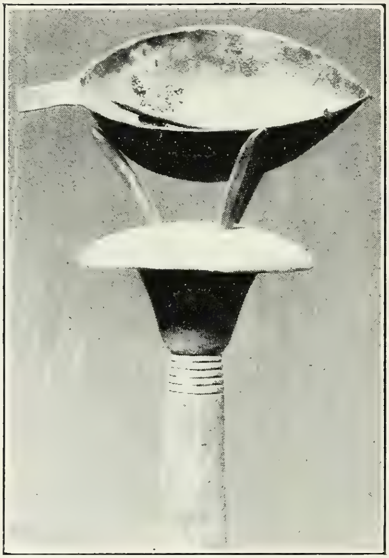


Fig. 27.

Fig. 22.

The making of splint lights must have assumed, about the seventeenth century, the proportions of an important industry in Europe, judging from the specimens that have been preserved. The holders, or fixtures, passed through successive stages of evolution until elaborate forms like those shown in Fig. 3, appeared—with ash pans, vertically or horizontally adjustable arms, and even chimneys, all to improve an illuminant that was, at its best, little better than the primeval fire-brand. Huge clumsy planes, some of which required four men to operate them, were commonly used in preparing the fuel for these archaic lamps. Splint-holders furnished light for king and for peasant, just as our modern illuminants are found in both cottage and mansion.

Owing to its wide distribution, wood, especially resinous woods, such as pine, was pretty generally used as a source of light in former times. Various vegetable substances were also burned in their crude state in the localities where they were most abundant. The Malays used a torch consisting of a piece of resinous gum wrapped in palm leaves,—a sort of candle with the wick on the outside. The East Indian candle-nut, or candle-berry, which yields two oily seeds that are burned for light by the natives, may also be mentioned in this connection. Oily carcasses of fish and birds have been used as lamps or torches of a crude sort. The stormy petral with a wick in its bill is burned for light in the Orkney Islands. A "candle-fish" held in a split stick has been used in Alaska.

THE CANDLE.

From these primitive candles it was but a few steps in evolution to the true candle, although just when or by whom those steps were taken is as unknown as the name of the man who invented the bow and arrow. The Patent Office records of that day and age have passed into oblivion.

It is known, however, that wax-candles* (*cereus funis*) were known to the Romans, as early perhaps as the beginning of the Christian era. The tallow candle (*sebaceus*) was probably of later invention, being mentioned in the writings of Apuleius, a second century author.

[2] Wax candles may be of Phoenician origin. See art. by Dr. C. Richard Böhm, *Lond. Ill'g. Engr.*, Feb., 1908.

The not infrequent references to "candlesticks" in the Bible have given rise to an erroneous impression in the minds of some persons regarding the antiquity of the candle. The fact is that all these references should be translated "lamp stand" rather than candlestick.

Candles also came into use in Japan and other Oriental countries at an early date. With the rise of the Christian church in Europe, the candle became inseparably associated with the lore of the church, and the candle-stick, with its myriad diversified forms and appurtenances, became, for a thousand years or more, the most familiar lighting accessory.

Tallow candles have been for centuries an article of domestic manufacture.

Rush-lights, *i. e.,* rushes dipped in tallow, were undoubtedly of very early invention,—earlier perhaps than the candle itself. They were well known in Pliny's time,* and have remained in use, notably in England, almost up to our own day.

Innovations or noteworthy improvements in candle-making were conspicuous by their absence throughout the Middle Ages, when the famous guilds of the waxchandlers and the tallow-chandlers flourished, and indeed up to comparatively modern times. Early in the 18th century the pursuit of the sperm whale was begun, and spermaceti was first used as a substitute for tallow about 1750. Nearly a hundred years more elapsed before the first important step was taken towards the elimination of those erstwhile necessary nuisances, the snuffers. Composite candles, or "composites," composed of stearic acid and stearin, were first manufactured about 1844. This change in the material used for candle-grease, together with a change in the design of candle wicks from a circular to a more or less elongated cross-section, and the pickling of the wicks in salt resulted in practically complete combustion of the wicks and the relegation of snuffers to the rubbish heap, the attic, and the antique shop. Composites are now commonly made of stearin and paraffin, the composition being varied according to the climate whither the product is to be shipped. Indeed, with the development of elaborate candle-

[3] E. B. Taylor's Anthropology, Chap. II, p. 273.

moulding machinery in recent years, the ancient trade of candle making has now evolved into an exact science.

To enable him to work at night with both hands free on his immense mural painting "The Last Judgment," Michael Angelo fitted a candle-socket to his cap, and with the aid of the flaring light from this weird portable, produced one of the world's master-pieces.

Although this paper deals with the evolution of the lamp rather than of the chandelier, it is of interest to note that one of the earliest forms of the latter was of natural origin—the "suspended antler" chandelier as shown in Fig. 19 (from the Swiss Museum in Zurich). From the suspended antler to the simplest manufactured hanging fixture was an obvious step, but it marked the birth of an industry. It is by no means uncommon in this twentieth century to see decorative electroliers consisting of antlers wired and equipped with incandescent lamps,—a rather striking example of the persistence of one of the earliest and most primitive kinds of fixture.

Space limitations forbid more than an allusion to the evolution of illuminants used in religious worship and ritual from the most primitive altar-fires down to such elaborately ornamented candlesticks as are shown in Fig. 20. The three large prickets came from Roman Catholic churches; the stick designated 27 is from an Oriental temple, while that marked 42 is practically an exact reproduction in form of the seven-armed lamp-stand in the ancient Jewish temple, so far as may be ascertained from the bas-relief on the Arch of Titus.

Fig. 21 shows what may be called a "link" between a lower and a higher development in the scale of illuminants. It is a combination candlestick and primitive oil lamp (from the Imperial Austrian collection). One may well believe that at one time such combinations were by no means uncommon, just as combination fixtures of quite a different sort are in considerable use to-day.

THE GREASE LAMP.

The oil lamp, while in many localities doubtless invented previous to, or without reference to, the candle, is nevertheless

so closely related to the latter, physically, that it may be treated as an outgrowth. In fact, there is an intermediate step between the candle and the liquid oil lamp namely, the grease or tallow lamp, a number of which are shown in Fig. 22.

Nor is it necessary to search far for a "missing link" between the candle and the grease lamp. In some of the historical collections may be seen a kind of candle holder having at its base a container worked in the form of a saucer to catch grease drippings from tallow candles; an auxiliary wick was placed in a depression in the rim of this grease-pan or container which could then be utilized as a grease-lamp.

It is probable that the burning of fat or grease in open vessels or braziers preceded the construction of the oil lamp proper, even in the earliest times.

Open soapstone saucers, burning grease, are depended upon for artificial light even to-day, in the land of the Eskimos, where such lamps have been in use since time immemorial. In fact, the Eskimo depends upon them for his very existence—for heat as well as for light.

The fuel used in these lamps is blubber, which the heat of the lamp itself causes to yield oil. The wick consists of moss, rubbed to a powder and carefully laid in a thin line along the saucer. "The flame," according to Dr. Hough,[4] is about 2 inches high, clear and smokeless if the wick is properly cared for."

THE OIL LAMP.

Probably the most primitive form of oil lamp was a skull in which fats taken from animals killed in the chase were burned, producing a fitful light and warmth. Probable remains of such lamps, according to Hopkins, have been found in the former abodes of cave-dwellers.

It is common to hear the "invention of the oil lamp" ascribed to the ancient Egyptians, chiefly perhaps on account of its ascription to them by Herodotus; and in view of the undoubted extensive use of oil lamps in the Nile country it is strange that so very few Egyptian lamps have been found. Fig. 27 shows one of these rare relics, discovered in the sepulcher of Ka, and

[4] "The Origin and Range of the Eskimo Lamp".

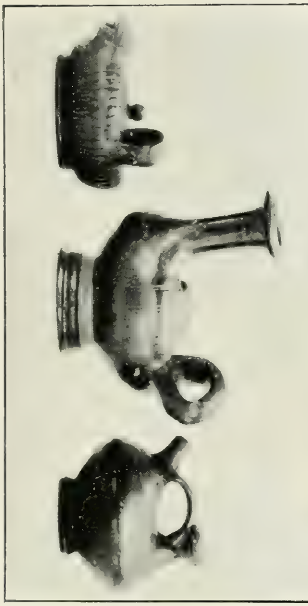


Fig. 29.

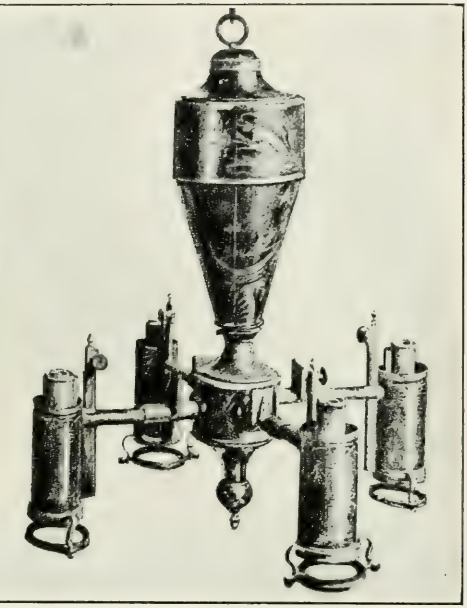


Fig. 41.

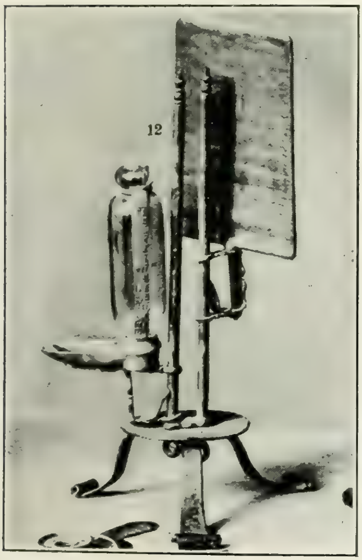


Fig. 39.

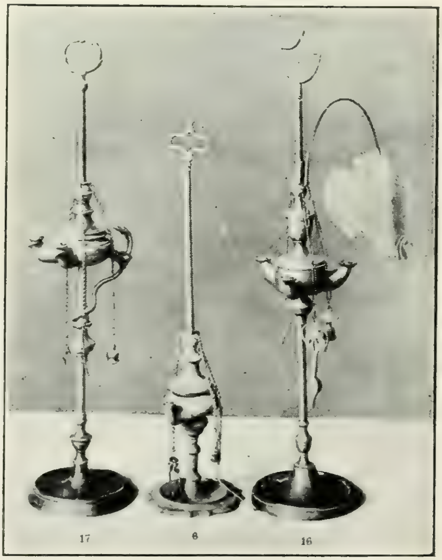


Fig. 40.

Fig. 43.

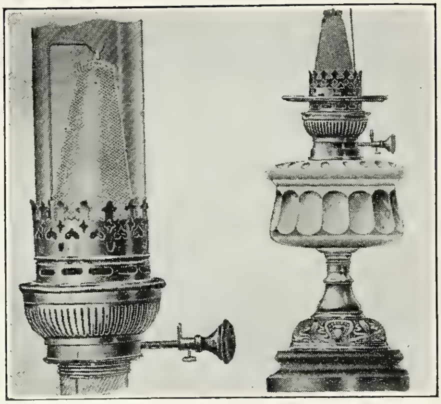


Fig. 44.

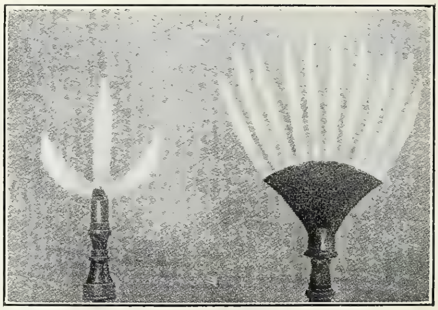


Fig. 47.

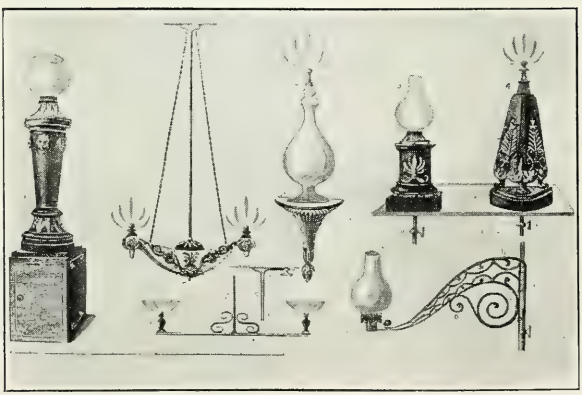


Fig. 46.

now in the Gizeh Museum at Cairo. It certainly evidences no great amount of artistic skill; the base is of limestone, the upright support of wood, and the lamp proper of bronze.

According to Herodotus, the Egyptians were using, at their sacrificial feasts, open saucers filled with salt and oil, with wicks that floated on the surface. At the same period asphaltic oil was collected from the surface of a lake on the island of Zante, off the Grecian coast, by means of myrtle branches which were allowed to drain into stone receptacles, the oil being used in lamps.

Discoveries by French archaelogists have shown that the oil lamp was in use at the close of the bronze age among the prehistoric lake dwellers of Switzerland, and up to the present time, according to Dr. Hough, these are the most ancient objects which have been found that are unmistakably lamps.

The collection of primitive oil lamps in the National Museum at Washington includes shell lamps from Japan and the Orkneys, and terra-cotta saucers from China, Syria, India, etc.

In tracing the evolution of the tubular spout for the lamp wick, one first finds a slight depression appear in the side of the saucer, —a rest in which the wick could be laid, as in the Egyptian lamp (Fig. 27) shown. This depression, in the case of terra-cotta lamps, was easily pinched into the form of a short tube. The so-called "Punic" lamp, of which many specimens have been found in Crete and elsewhere are among the very early forms. Finally, the spout emerges as a distinct part of the lamp, with a special name, as for example in the three Etruscan mortuary lamps, dating from about 400 B. C., shown in Fig. 29. These Etruscan lamps, which are now in the Carnegie Museum, Pittsburgh, are shown on account of their marked individuality, the middle one in particular being radically different from the small squatty lamps that were in general use among the Greeks and Romans.

The oldest lamps found in Rome date from the third century B. C., and are thought to be of Campanian fabric.[5] They are quite different from the ordinary types. It would appear, therefore, that the Romans originally borrowed their lamps from Southern Italy.

[5] See Walters' History of Ancient Pottery, chapter xx.

From about the first century B. C., the Romans, instead of making their lamps on the potter's wheel, as had previously been the practise both in Greece and Italy, almost invariably manufactured them from moulds, in a harder and finer clay than the pattern. The top of the lamp is ordinarily depressed, as a guard against overfilling.

While the making of lamps was considered but a lowly occupation by the ancients, yet those who pursued it often accumulated considerable wealth. Hundreds of specimens of the product of certain Roman lamp manufacturers have been found, each lamp stamped with the manufacturer's name or trade-mark. One L. Cæcilius Sævus, in particular, appears to have been a very prosperious magnate.

For special purposes lamps were made with a plurality of spouts, some specimens boasting of as many as eighteen or twenty. These were the "high candle-power clusters" of the ancient world.

Lead, alabaster marble, glass, and even amber lamps have been found. Tow, papyrus and linen were among the materials used for wicks.[6]

There was no really notable progress in lamp development from an evolutionary standpoint—no new principle enounced—for a period of perhaps 2,200 years, or until the appearance of the Argand burner in 1784. The ingenuity and talent which the modern lamp manufacturer expends in an endeavor to discover new principles, new materials, new processes, greater efficiency, a wider range of application, the ancient lamp manufacturer lavished in fashioning his lamps in curious, beautiful, symbolical, or grotesque designs and patterns. Thus among the subjects represented on Roman lamps are fishermen, ships in harbor, goatherds, gladiators, slaves and circus riders, while freak lamps were made in such curious shapes as pine cones, negroes' heads, gladiators' helmets, etc.

The principal point of difference between the lamps we have just been considering and those of the early Christian era is that in the latter, portrayals of the miracles of Scripture, and figures

[6] See Daremberg & Saglio's "Dict. des Antiquites," article on Lucerna.

of saints, supersede the satyrs and gladiators as subjects for lamp decoration.

While the oil lamps of the Middle Ages and of early modern times were mostly lacking in artistic merit as compared with the classical *lucernae,* they at least began to display traces of mechanical invention and of that same tendency to adapt the lamp to all sorts of specialized uses which has already been noted in connection with candlesticks.

An interesting lamp with a reservoir calibrated into divisions for the purpose of indicating the time is shown in Fig. 39. As the latter lamp is blessed with a shade, it may have been intended for the sick-room, although these "horological lamps" were probbly more often used as student lamps. In any case, they lend a very vivid significance to that hackneyed phase "the midnight oil."

Accordingly to D'Allemagne, there were many of these time-telling lamps in use in the 18th century; Father Lana had constructed a similar lamp in 1670. As chronometers, they lacked fully as much in accuracy as they did in satisfactoriness as illuminants.

Before taking up the evolution of the oil lamp late in the 18th century from a mere vessel with a spout—incapable of producing anything but a yellow, smoky, flickering flame—into a device scientifically designed to produce light, I might refer to the so-called Venetian lamps, which were in use in even as late as the 19th century. As seen in Fig. 40, they were made in a variety of very graceful styles, and are provided with little picks, extinguishers, and snuffers for regulating the wick, and sometimes in addition with shades. They are the final development of the ancient ideals in lamp manufacture.

The principal trouble with the archaic vessel and spout variety of oil lamp was that the form of the flame was not such as to permit a free enough access of air for adequate combustion. This fact, due to the ill-suited solid cylindrical wick, together with the lack of a chimney to produce a draft, meant a low-temperature, wavering flame.

In 1783, Leger, a Parisian scientist, is said to have devised the flat wick and burner that survived in the small hand lamps

for kerosene which we can all remember stood on the kitchen shelf. As far back as the 16th century a philosopher named Cardan—"the first of the moderns," we may call him, from a lamp improvement standpoint—had devised a lamp with an elevated oil tank and gravity feed, a scheme especially adapted for heavy oils. Both this idea and that of the flattened wick, together with a new conception, that of creating a draft right up through the center of the burner, were used by the Genevan physicist Argand in his invention of the justly celebrated Argand burner in 1784. Fig. 41 shows an early fixture with Argand lamps. Note the clumsy mechanical arrangement for raising the wicks; the screw burner had not yet been developed. Argand, let it not be forgotten, was a research engineer, with a good technical education for his day; and his memorable invention was made while he was engaged in experimental work in certain French distilleries. The laboratory of the specialist has ever been a birthplace of notable developments in the means of illumination.

The lamp-chimney, first of metal, supported above the flame, and later of glass, supported on a perforated gallery, was the next development—almost an obvious one, to improve the draft of the Argand burner. So indispensable a feature of the lamp has the chimney since come to be regarded, that the following incident, for which the writer will vouch, occurred in a Kansas store not long since. The "oldest settler," tottering up to the counter and picking up a tungsten filament incandescent lamp, drawled out "Does these hyar new chimbleys give more light than them old 16 horse-power ones they uster burn?"

During the early years of the 19th century, whale oil was chiefly depended on for consumption in lamps, and whales were already becoming scarce. A chimneyless double flat wick, similar in shape and size to lamp shown in Fig. 43, was used for the whale oil.

About 1857 petroleum was struck in Pennsylvania, and in '59 the American petroleum industry received a strong impetus by Col. E. L. Drake's successful borings, which opened up a boundless supply of illuminating oil at prices with which whale-oil could no longer hope to compete. The first American

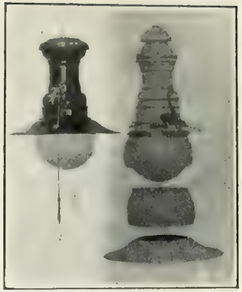


Fig. 49.

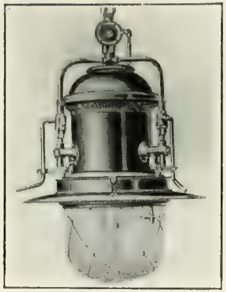


Fig. 50.

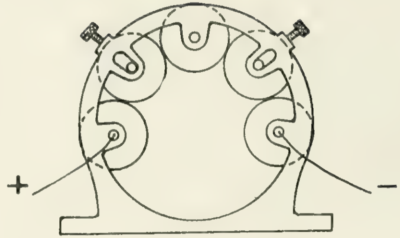


Fig. 52.

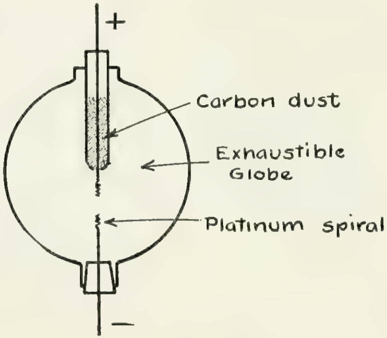


Fig. 59.

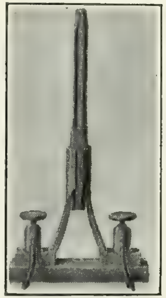


Fig. 54.

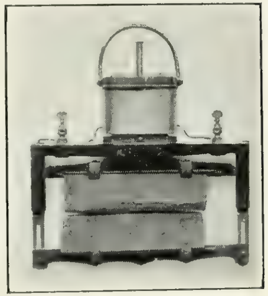


Fig. 53.

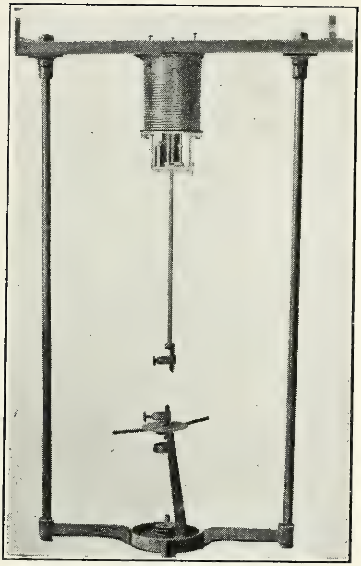


Fig. 55.

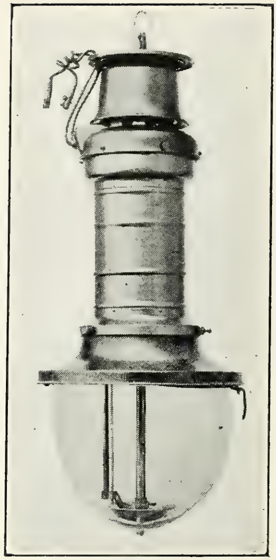


Fig. 56.

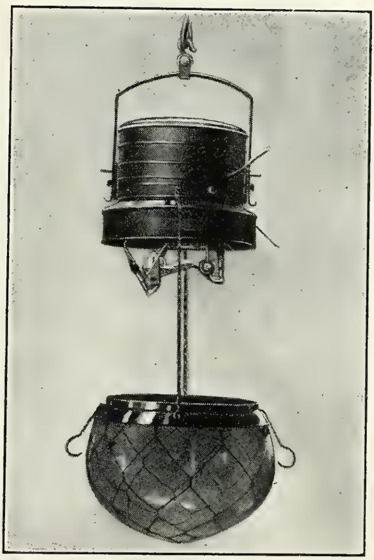


Fig. 57.

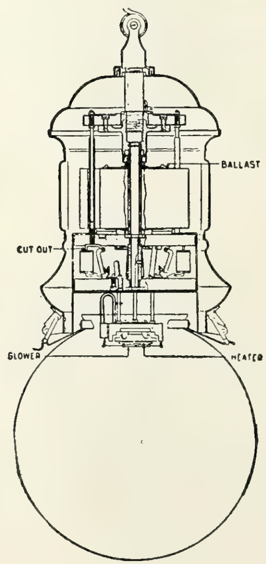


Fig. 58.

patent on a petroleum lamp was taken out in this same year. As the sperm whale had now become so exceedingly scarce that the hardy whalers were forced to push their pursuit of it into the Arctic and Antartic Seas, the introduction of kerosene as a cheap substitute for the costly whale-oil was indeed fortunate. It was at least a better substitute than that murderously explosive combination of turpentine and alcohol known as "camphene," or "patent fluid," which had come into competition with whale-oil to a considerable extent. A camphene lamp is shown in Fig. 43. Note the long tubes.

The different kinds of oil lamps that might be alluded to, including lamps in which heavy oils had to be pumped mechanically to the wick, are legion.

Fig. 44 shows another so-called "link" in the chain of illuminants,—namely, the oil-gas lamp, although it is in no sense a chronological "link." From the standpoint of luminous efficiency, lamps of this general type, in which the oil is used to impregnate a current of air, thus forming a gas that is burned under a small incandescent mantle, represent the latest development of the oil lamp. The particular lamp shown is of German manufacture.

THE GAS LAMP.

Coming to the gas lamp proper, it may safely be asserted that no other class of lamp has had a more logical history. Starting with the simplest sort of an orifice in a bladder or pipe—a mere outlet for gas under pressure—the experiments of specialists have caused it to evolve from this simple but inefficient form into one that is relatively complex, yet far more efficient—namely, the inverted mantle burner. It has been an evolution in every sense.

The modern practise of obtaining light from a medium transmitted from a distant generating point originated, of course, with the gas industry, and one hundred years ago had hardly begun to be known. The use of pipes and distributing systems had been more or less familiar to civilized peoples since remote antiquity. Remains of ancient waterworks systems are well known. Indeed, it seems probable that the Chinese had learned to pipe natural gas from salt mines through tubes of bamboo, and to use it for

local lighting purposes centuries before the word "gas" was invented. These Chinese, however, did not have the central station idea, nor is there any record of their manufacturing gas for illumination or any other purpose. They "staked out the claims," it would appear, to a good many of our modern inventions, and then failed to "improve the property."

It is a curious fact that the first important experiments on artificial illuminating gas form a direct line of evolution from experiments on natural gas. There was, it appears, for many years, a natural gas-well underlying a ditch of water near Wigan, in Lancashire, England. The water was continually bubbling and heaving, causing, undoubtedly, many superstitious beliefs among the good folk of the neighborhood.

In February, 1659, Mr. Thomas Shirley, impelled by a desire to obtain some scientific data on this unruly "spring," made the significant discovery that the phenomena "did arise from a strong breath, at is were a wind."

It is indicative of the ignorance which existed for milleniums concerning substances in the gaseous state, that a generic name had to be invented for them as soon as scientists really began to make their acquaintance, so to speak. They had been known almost indiscriminately by such terms as "spirit," "breath," "vapor," "halation," "wind," "Spiritus Sylvestris," etc. Van Helmont (1577-1644) was the man who "invented gas"—that is to say, he invented the word, which, after being almost forgotten, was resurrected and extended in its meaning by Lavoisier, about 175 years later.

Shortly after Shirley's researches, another person of enquiring disposition, the Rev. Dr. John Clayton, turned his attention to the "ditch," near Wigan, and made some momentous discoveries. In an historic communication to the famous scientist Robert Boyle, written probably about 1664, he tells how he caused the bubbling water to be drained off, whereupon the inflammable gas continued to emanate from the ground itself. There was a coal-mine nearby, and Dr. Clayton suspected some connection between the two circumstances. Accordingly, he distilled coal in a retort, and was successful in collecting the coal-gas in bladders.

In his letter to Boyle he refers specifically to the luminous power of carbureted hydrogen.

For more than a century after Dr. Clayton's use of artificial gas as an illuminant, the gas light was unheard of except in scientific circles. Jean Pierre Minckelers, professor of natural philosophy at Louvain, Belgium, was commissioned by the Duke of Arenberg, in 1784, to experiment on means of producing light gases for balloons, which had just been invented. Minckelers distilled many substances, including coal, published an account of his "discovery" of the gas light, and in 1785-6 lighted his lecture-room with gas. On this account he is recognized by the Dutch as the inventor of gas lighting, and in 1904 a statue in his honor was unveiled at his birth-place. Professor Minckelers, however, and Professor Sickel of Würzburg, who is also said to have illuminated his laboratory with gas in 1786, did not carry the practical science of gas lighting much beyond the point where Dr. Clayton left it in 1664. Their lamps were probably simple, inefficient jets.

The author does not care to embroil himself in the interminable international debate as to whether the redoubtable title of "Father of Gas Lighting" really belongs to William Murdoch, the Cornishman, or to Philippe Lebon, the Parisian.

For six years (1792-8) Murdoch was experimenting at his home with apparatus for distilling different kinds of coal. He lighted his own house in 1792 by coal gas. While he was thus industriously making his preliminary experiments, Lebon, in Paris, was no less industriously, and independently, elaborating his "Thermolampe," which he patented in 1799. This "Thermolampe," was a self-contained affair for the production of illuminating gas by distillation from wood, coal, etc. Lebon, and his widow, who took up her husband's work after his early demise, never got much further than the lighting of a few houses and gardens in Paris, although unsuccessful attempts were made to market the "Thermolampe" in America. Lebon had, however, a disciple named Wintzler who deserves to be called the "Father of the Central Station idea," for he caught a vision of the possibility of lighting a whole city, and, coming to London, became the enthusiastic promotor of the first company in the

world to supply lighting service to the public through a system of distributing mains.

Those first gas mains would, to be sure, provoke the mirth of a modern engineer. The principal mains laid in 1815 in the world's largest city were but 2 inches in diameter. Wrought iron pipes were unknown, and many house services were formed of musket barrels, threaded and connected up in series, muzzle to breech.

Meanwhile Murdoch, after his six years of private experimentation, had entered the employ of Boulton and Watts, pioneer engine builders, with whom he continued his researches. The principal building of their factory at Soho was illuminated by gas in 1798, and in 1802, as a great public spectacle in celebration of peace between France and Britain. The towers of the factory were illuminated with bengal lights (*i. e.,* flaring open burners) and, to quote a writer of the day, "the whole front of that extensive range of buildings was ornamented with a great variety of devices that admirably displayed many of the varied forms of which gas light is susceptible."

The first extensive experiments on the economy of different sorts of gas-burners were conducted under the auspices of Boulton and Watts, who went into the matter, as they considered, quite exhaustively, laying out over $200,000 on experiments. Murdoch used tallow candles consuming 175 grains per hour as standards in measuring the candle-power of his burners with different qualities of gas.[7]

The earliest gas burners were designed to produce flames like those of tallow candles and oil lamps.

Fig. 46, taken from the original (1815) edition of Accum's Treatise on Coal Gas, shows some of the gas burners of the day. The "cockspur" and "cockscomb" burners (see Fig. 47), and the Argand burner, an adaptation of the Argand principle to gas lamps, were popular early forms. Burners were rated in "pounds"—a 4 1. burner, for example, being an Argand burner of a size for which gas service was supplied at a charge of 4 pounds per year,—not a very flexible system, but it must be remembered that the gas meter had not yet been introduced.

[7] See paper by E. L. Nichols, TRANS. I. E. S., 1905. p. 844.

The common batswing burner, which causes the flame to take the form of a thin sheet, evolved directly and naturally from the cockscomb burner. Not until 1820 did J. B. Nielsen discover the principle of the fish-tail burner, namely that two jets of flame can be made to impinge so as to spread themselves into a fan-shaped sheet of flame. While no more efficient than the batswing, the fish-tail burner gives a higher, better shaped flame, and hence was more suitable for use with globes.

While the evolution of the gas lamp, if judged superficially, was not very rapid during the first half of the nineteenth century, important experimental work was done which paved the way for the introduction of the mantle and mantle burner. Goldsworthy Gurney in 1826 showed that a cylinder of lime became dazzlingly brilliant if the flame of an oxy-hydrogen blowpipe were caused to impinge upon it,—a fact which Henry Drummond, shortly after, put to practical use in his famous "lime-light." Nine years later W. H. Fox Talbot discovered that even an alcohol flame will heat lime to incandescence, if the latter be sufficiently finely divided; this he accomplished by soaking blotting-paper in a solution of a calcium salt and later burning out the paper.

Gillard, who introduced the intermittent process of manufacturing water-gas in 1848, came even closer to the practical mantle. His gas gave a blue, practically non-luminous flame, hence he devised a mantle of platinum gauze to fit over it, but the useful life of the lamp thus constructed was only a few days.

About 1855, Dr. R. W. von Bunsen invented the atmospheric, or "Bunsen" burner. It was while experimenting in Dr. Bunsen's laboratory at Heidelberg, thirty years later, that Karl Auer von Welbach discovered the practicability of improving the luminous efficiency of the gas lamp by the use of mantles made by saturating cotton fabric in a solution of certain salts and burning out the organic matter. His early mantles, which were made with erbium salts, gave a pronouncedly greenish light, and it was several years before the ingredients and their proportions for a thoroughly successful commercial mantle were finally worked out. The thoria-ceria mantle, placed on the market in 1890, finally overcame the difficulty.

As has proven true also with tungsten-filament electric lamps, the earlier gas mantles were considerably more fragile than the improved product of recent years. In consequence of this fragility many so-called "anti-vibration" burners were contrived. About 1900, the practical inverted Bunsen burner (Fig. 49) was evolved and shortly afterwards came the inverted mantle gas lamps which soon so generally superseded the upright.

The gas mantle has, of course, stimulated the use of natural gas and lean gases for illuminating purposes.

It would be out of the question here to review in detail the schemes for improving gas lamp efficiency that have been exploited with varying degrees of success since the introduction of the gas mantle. Prominent among these are the pre-heating of the gas before it reaches the burner, and the use of high-pressure air or high-pressure gas to obtain a more intimate mixture, more perfect combustion and higher candle-power, as in the lamp shown in Fig. 50.

So much for the gas branch of the lamp family. Before tracing the evolution of the electric lamp, mention should be made of special illuminating gases such as acetylene, and gases liquefied under pressure, of which "Pintsch gas" is an example. Acetylene (C_2H_2) is a comparatively recent chemical discovery, the possibility of its generation from calcium carbide having been first demonstrated by Thomas M. Willson in 1892. The common acetylene burner, with its ducts for admitting the necessary air for the proper combustion of this very rich gas, is too familiar an object to need illustration here.

THE ELECTRIC LAMP.

As the early scientific work on coal-gas was prompted by the investigation of a burning well of natural gas, similarly the early researches that paved the way for the electric light are linked up to lightning, and the other natural manifestations of that light, through the classic experiment of a tallow-chandler's son,—Benjamin Franklin, who flew the historic kite in 1752. And as a century and a quarter elapsed between the investigation of the Wigan gas-well and the commercial beginnings of the gas-light ing industry, so nearly a century and a quarter elapsed between

Franklin's experiment and the first electric lamp to be extensively commercialized. I refer to the Jablochkoff "electric candle," which was brought out in 1876, patented in many countries, and widely used for several years.

It should not be inferred that there were no electric lamps between Franklin's time and Jablochkoff's. Far from it. But these lamps may be divided into three classes: (1) those which were entirely impractical; (2) those which possessed considerable merit, but were confined to the scientific laboratory by the fact that no cheap method of generating the necessary electric current was then known, and (3) those which found restricted commercial application, as in lighthouse service, photography, etc.

During this period at least one inventor, young Starr of Cincinnati, hampered by the lack of a practical current supply, literally worked and worried himself to death in attempting to solve the problem of the incandescent lamp; another, Henry Goebel of New York, made electric lamps without suspecting that there could ever be a world market for them.

The electric arc lamp, of course, suffered under the same limitations as the incandescent. Discovered in 1801 by Davy, the arc light was not publicly exhibited until 1809, when, the dynamo being unknown, Davy's mammoth battery of 2,000 primary cells served as a cumbersome source of current.

Perhaps a description of the first arc lamp patented in England (the Wright arc of 1845) may be of interest. It consisted, as shown (Fig. 52), of five carbon discs in series, of which two were movable by means of hand-screws serving to draw out the four arcs. No less curious is the Wallace arc shown in Fig. 53, a type which, in conjunction with the Wallace-Farmer dynamo, was used for street lamps in Baltimore in the late seventies.

The Jablochkoff candle (Fig. 54), as the first electric lamp to be extensively commercialized, is a sufficiently prominent link in the evolution of the lamp to warrant a little further attention. These candles were ordinarily operated on alternating current; lamps intended for direct current operation had to have the positive carbon twice as large in cross-section as the negative. Many substances were tried out for the barrier between the two carbons,—analogous in some respects to the "wick" of a tallow

candle. A mixture of sulphate of lime and sulphate of barytes was finally adopted. The rated life of the various types of Jablochkoff candle, which worked on a voltage of about 42, varied from 1 hour and 20 minutes to 3 hours and 20 minutes. Copper coating of the carbons was found to increase their life.

The invention of a really practical direct current dynamo by Gramme in 1870 marked the beginning of the period which saw the electric lamp break into the company of everyday illuminants.

Charles F. Brush of Cleveland, exhibited his first arc lamp with the wonderfully simple ring-clutch feeding arrangement in 1877 (see Fig. 55), and in the following year brought out his series arc dynamo, and started campaigns of arc light introduction in both hemispheres. Four years later Brush arc lamps were in regular operation in Shanghai and Tokio. Many other manufacturers entered the field. The arc lamp had come into its own.

The invention of the practical enclosed carbon arc lamp was announced at a convention of the National Electric Light Association in 1894, when Mr. L. B. Marks described the first lamp, which he had patented, embodying the points that made the inner-globe arc, for a period of about ten years, the favorite unit for high candle-power electric lighting in America.

Five years later the Bremer flame arc lamp was announced, and was soon followed by other types of lamps having impregnated electrodes or electrodes of special composition, designed to increase the luminous efficiency and intensity. Fig. 56 shows a well-known form of the general class of lamps just mentioned. This brings the evolution down to "modern times" as regards the arc branch of the genealogical tree, except that the mercury-vapor arc has not been mentioned. Originated in 1892 by Arons, although suggested at a much earlier date,[8] this special case was later developed by Cooper-Hewitt to a point of commercial practicality. The more recent construction of mercury lamps with quartz tubes, thanks largely to the work of the German Heraeus, by improving the color and efficiency of the light, gave rise to the most recent steps in the evolution of this branch of the family (see Fig. 57).

The Jablochkoff candle was in a way the forerunner of the Nernst glower lamp, for Jablochkoff observed, doubtless while

[8] See W. S. Franklin's "Electric Lighting."

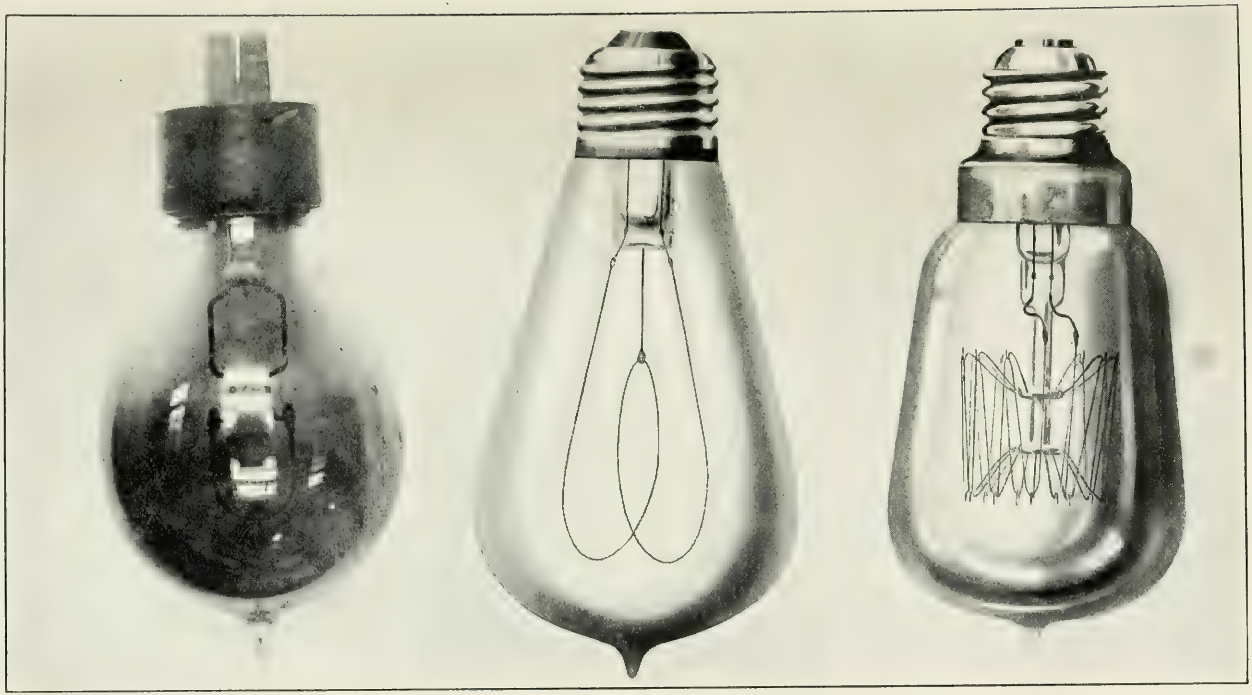


Fig. 66. Fig. 64. Fig. 63.

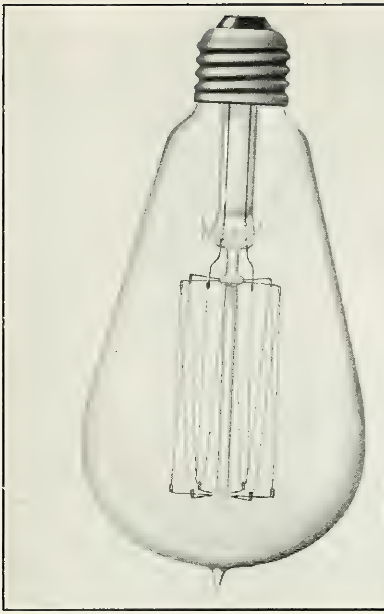


Fig. 68.

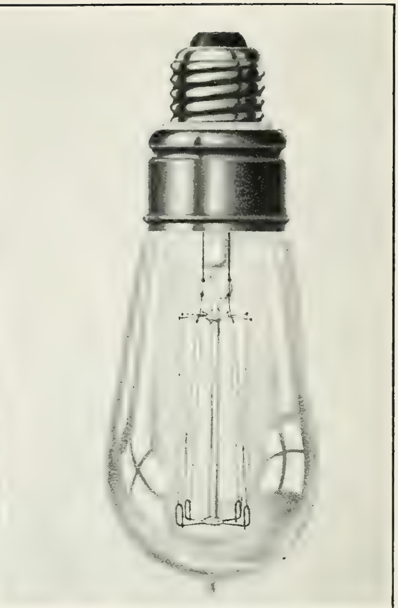


Fig. 65.

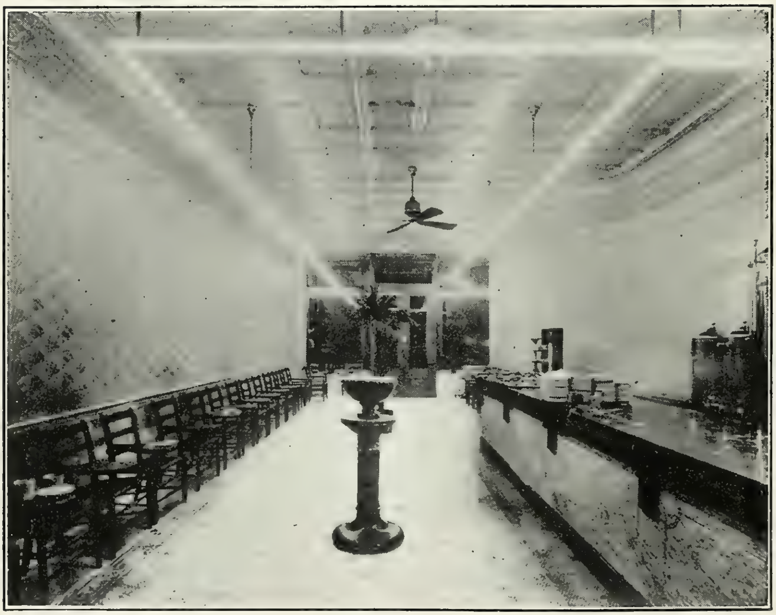


Fig. 69.

experimenting with different compositions for the so-called "wick" of his candles, that kaolin, magnesia, and several other substances normally non-conducting, became conductors when hot, and he succeeded in incandescing a strip of kaolin as far back as in 1877, and actually constructed a lamp on this principle in 1879. Twenty years, however, elapsed before the same principle, under the hand of a distinguished chemist, Dr. Nernst, was utilized as the basis of a commercial lamp (Fig. 58). One of the main difficulties, of course, to be overcome was the tendency of the glower to "run away," technically speaking,—*i. e.,* to become overloaded and burn out as its resistance, with increasing temperature became less and less.

From what older illuminant did the incandescent filament lamp evolve? The answer to this question is that, in so far as it may be said to be an outgrowth at all, it is an early offshoot from the arc lamp "stem." Numerous attempts, some of them involving much ingenuity, were made to produce the so-called "incandescent-arc" lamps that would work satisfactorily, and much money was sunk in valueless patents. One lamp of this sort was De Moleyn's. The lamp consisted of a glass globe with plugged openings for connection to a vacuum pump; through the upper end of the globe a tube containing carbon in finely powdered form was tightly inserted; a movable copper wire runs the length of this tube and through the orifice at its lower end, the said orifice being just large enough to allow the carbon dust to trickle through slowly, making contact with the platium spiral electrode that comes up through the bottom of the globe.

With the record of the "incandescence-arc" contrivance just described, and of many others equally impractical, before them, Swan, Edison, Sawyer, Man and Lane-Fox, all of whom were working on the incandescent lamp problem in 1879, at least knew some things to avoid. That same year witnessed the solution of the problem, and the exhibition of a complete system of incandescent electric lighting. Fig. 60 shows an early carbon filament lamp. This lamp was made before the art of "pasting" the filament to the leading-in wires was known; at that time the filaments had to be attached by clumsy mechanical devices of various sorts, such as tiny bolts, nuts and washers, or special shaping of

the filament ends, which were then clamped into the flattened ends of the leading-in wires. Furthermore, it was thought necessary to use thick wires of platinum, nearly an inch long, in the seals, adding very materially to the cost of the lamps.

In 1891 the cellulose process of making carbon filaments was developed, and two years later the cellulose filament was generally adopted in place of the bamboo. An Italian, Arturo Malignani, devised the "chemical exhaust" in 1895, enabling the average quality of incandescent lamps to be improved, and reducing both the expense of their manufacture and the price to the consumer. Meanwhile the process of "treating" filaments in hydrocarbon vapor to render them more uniform and improve their radiating properties had been introduced.

As facilities and experts for conducting research multiplied with the growth of the industry, improvements, first of minor importance, but in recent years of a revolutionary nature, were evolved. The substitution of moulded bulbs for "free-blown" bulbs, about 1892, and the invention of the turn-down lamp in 1898, belong, relatively speaking, in the category of minor improvements. The first exoteric evidence that the metal filament lamp might eventually supersede the carbon came about 1898, when Dr. Welsbach produced his first osmium filament lamp. Curiously enough, tungsten had been tried for filaments as early as 1889 by Lodyguine and Tibbets, but without success, as these experimenters did not realize the necessity of extreme purity for the metal.

The discovery of ductile tantalum was announced by von Bolton in 1901, and the first experimentally successful tantalum lamp was built a year or so later, although tantalum lamps (Fig. 63) were not in a condition to be placed on the market for several years more.

Meanwhile, in 1905 the Gem (metallized carbon) lamp (Fig. 64), which had been developed in an American laboratory, made its appearance, and served as a sort of stepping-stone to the lamps of still higher efficiency that were about to make their appearance.

In 1907 came the pressed-filament tungsten lamp (see Fig. 65), a curiosity that one hardly dared look at for fear of breaking it,

or dared buy for fear of "breaking" ourselves. This lamp was gradually evolved into the strong, durable, cheap drawn-wire lamp of to-day (Fig. 68). The very newest line of development, *viz.*, the use of bulbs filled with an inert gas instead of a vacuum, with a resulting efficiency of about 0.5 w. p. c. should greatly broaden the usefulness of the tungsten-filament lamp, particularly in the direction of very high candle-power units, say 1,500 candle-power and above—a field heretofore not covered by incandescent lamps.

One class of electric lamps remains to be mentioned, namely the high-tension discharge tubes containing rarified gases, as for example the nitrogen and carbon dioxide tubes (Fig. 69) of Moore and the neon tube lately heralded from France. While such tubes represent a unique departure in lamps as regards the dimensions of the light-source and the high voltages skilfully managed, yet they must be regarded as closely akin to, and doubtless suggested by, the small Geissler tubes used in college lecture-rooms to demonstrate the phenomena of electric discharge through a partial vacuum.

CONCLUSION.

In this review the evolution of the lamp has been traced from a mere fire-brand or stone saucer, not indeed to its culmination, which none of us may expect to see, but to its modern exponents in the oil, gase and electric branches of the family. A broad view of the lamp's past history must confirm the opinion that development has not come to a halt, but on the contrary is proceeding at a rate that to former generations would have seemed astounding.

A hardly less fascinating story than that of the lamp would be the evolution of the reflector, from the simple flat circular candle-shades of former times to the wonderfully efficient commercial reflecting and diffusing media that are to-day available in addition to the wide range of beautiful shades intended primarily for decorative purposes. The vehicle lamp, the signal light, and the street lamp are further examples of progressive development which, owing to their specialized nature, cannot be taken up here. Mr. Albert Scheible has outlined the progress of street

lighting from the days of the linkman with his torch to our modern "white ways."[9]

Except for a few short sighted surmises, based on theoretical considerations or on our knowledge of promising experimental work now being done in the laboratory, the interrogation point is, after all, the most that any of us can offer. We can, however, say with practical certainty that the better lamps of the future, whatever they may be, will owe their betterness to the concentrated research work of expert scientists in the great development laboratories existing for this specific purpose. Such men as Argand, Murdoch, Lebon, Boyle, Faraday, Bunsen, Welsbach, Steinmetz, von Bolton and Feuerlein, Just and Hanaman, and a host of others too numerous to mention, each specializing with all his might on some particular phase of research, have evolved the lamps of to-day. To encourage, therefore, and to foster all scientific research along illuminating engineering lines, even if such research can promise no immediate commercial result, would seem the surest way to speed the lamps of tomorrow. Happily there are a number of laboratories in existence where such research work is being carried on by scientists well equipped for their respective tasks. These men are unconsciously evolving the lamps of our descendants.

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NOTE:—For the reader's convenience, after each reference is placed a Roman numeral, I, II, III, IV, V or VI, indicating the period or periods in the history of the lamp with which the reference chiefly deals. The numerals have the following significance:

I................Entire history previous to Christian Era.
II................A. D. 1–A. D. 1000.
III................A. D. 1000–A. D. 1500.
IV................A. D. 1500–A. D. 1800.
V................A. D. 1800–A. D. 1900.
VI................A. D. 1900 to date.

[9] *Elec. Rev. & W. Elec.*, April 1, 1911, et. seq.

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Histoire du Luminaire............	D'Allemagne	II, III, IV
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Guide to Brit. Mus. Exhibit illust. Greek & Roman life..........		I, II
The Lamp of the Eskimo*........	Hough	V
The Origin and Range of the Eskimo Lamp	Hough	V
Guide to Early Christian & Byzant. Antiquities of the Brit. Mus.		II, III
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History of the Introduction of Gas Lighting	Hunt	III, IV, V
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* Monographs in phamplet form are designated by the asterisk (*)

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Note:—In several instances, the topic of special interest in connection with this paper is noted below, rather than the actual title, which may be necessarily too comprehensive for this purpose.

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Lectures on Illtg. Engrg.: Gas Ltg. (Johns Hopkins, 1910)	Cowdery	IV, V, VI
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SOME ENGINEERING FEATURES OF OFFICE BUILDING LIGHTING.*

BY EVAN J. EDWARDS AND WARD HARRISON.

Synopsis: This paper deals with various arrangements and types of reflecting units installed in offices of the same size and finish, where the conditions for careful testing are especially favorable. The results of illumination tests are shown for the various systems on a basis of equal quantity of light flux generated and also in terms of the wattage which would be required to give an average intensity of 5 foot-candles. The character of the walls and ceiling surface is fully described and the results of surface brightness tests are tabulated so as to indicate the contrasts which exist with the various systems, and are given on a basis relative to white blotting paper and also in absolute values. The illumination values are not corrected for a known photometer error but the error is especially called to the attention of the reader as something to be taken up by the authors later, but these incorrected illumination values should check with similar tests carried on in the usual manner. Corridor lighting, loss of light due to dust collection and effect of room size on utilization factor are touched upon; and data relating to installations of steel reflectors in basement spaces are given.

In designing the illumination for a group of new office buildings at Nela Park, Cleveland, attempting to make the best use of the recent developments in lamps and accessories, many interesting questions of illuminating engineering have presented themselves. Since illuminating engineers have often expressed their interest in data obtained in actual installations and their regret because of the scarcity of such figures, it seems desirable at this time to go into detail in giving test figures and in comparing the results.

The purpose of the paper, then, is to add something to the available fund of recorded illuminating engineering data, rather than to describe in detail the methods used in the installation in question.

The opportunities for making comparisons between alternative designs and also for obtaining accurate results are in this case exceptional in many respects. Some of the standard office spaces

* A paper read at a meeting of the Pittsburgh Section of the Illuminating Engineering Society, June 16, 1913.

occupied by the engineering department are provided with both center and four-per-bay outlets and all distributing circuits, either as a whole or individually, may be switched over to special test circuits terminating at plug boards which may be connected with any kind of current supply required. Since many of the offices are occupied by those particularly interested in illuminating engineering, a number of different designs which are considered good have been provided to suit individual tastes. Thus, there were available for test, installations of various kinds from which directly comparable results could be obtained, particularly in cases where different equipment could be installed in the same room.

The lamps used for tests were selected so as to give their rated candle-power when operated at the test voltage. The voltage for the test circuits was regulated by hand, thereby doing away with the necessity for voltage-candle-power corrections. In the tests which will be directly compared, the same lamps were used except where one test required clear lamps and the other bowl-frosted. The bowl-frosted lamps were rated before being frosted and the "clear" values used in computations.

Photometric readings were taken with a Weber portable photometer. The stations for all tests were as given in the plans of Figs. 1-6.

The instrument was calibrated by using light incident normally on the test plate. Investigation, which is at present nearly finished and which will be presented in due time, shows that the readings, as given, are smaller than the true values by about 12 per cent. due to the failure of the photometer screen to give full value to the light which reaches it at oblique angles. Since all of the best photometric test plates so far investigated show essentially the same characteristics, the illumination values tabulated should be reproducible by anyone working under similar conditions.

With the thought in mind that contrasts on the walls and ceiling are important factors in an illumination design, surface brightness readings were taken at what appeared to be the brightest and dimmest spots. These are given in terms of equivalent foot-candles on white blotting paper, for the reason that it is a

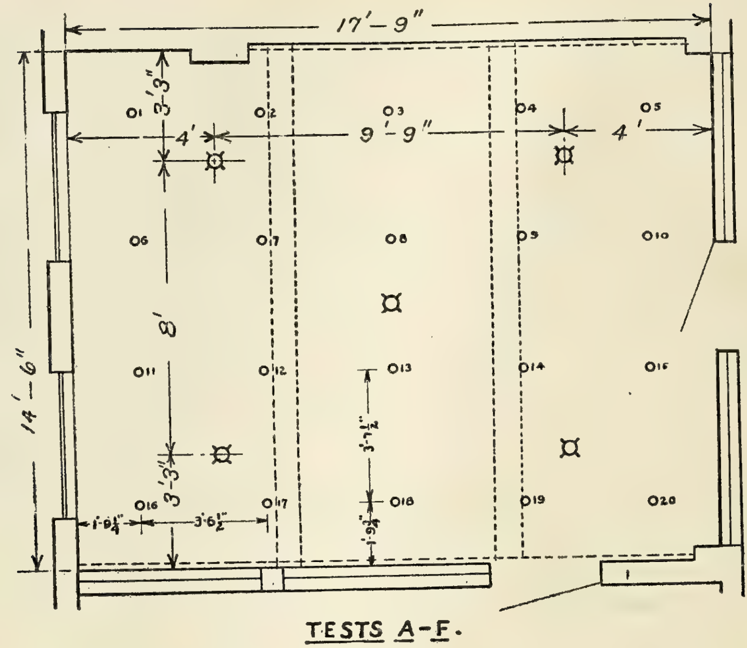

17'–9"
3'3"
4'
9'–9"
4'
8'
14'–6"
3'7½"
3'3"
1'9¼"
3'6½"
1'9¼"
TESTS A–F.

Fig. 1.

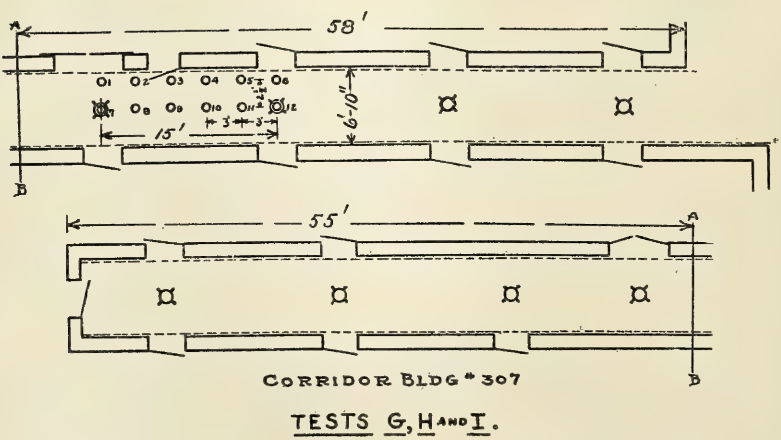

58'
6'-10"
15'
55'
CORRIDOR BLDG # 307
TESTS G, H AND I.

Fig. 2.

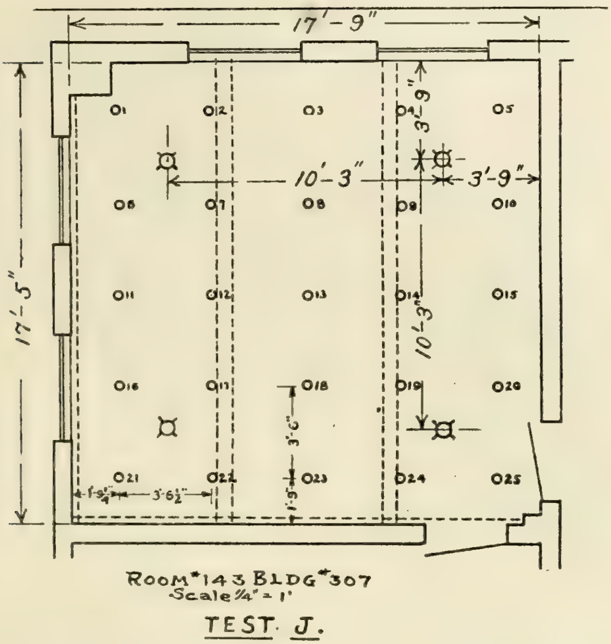

17'-9"
17'-5"
10'-3"
3'-9"
3'-9"
10'-3"
3'-6"
ROOM #143 BLDG #307
Scale 1/4" = 1'
TEST J.

Fig. 3.

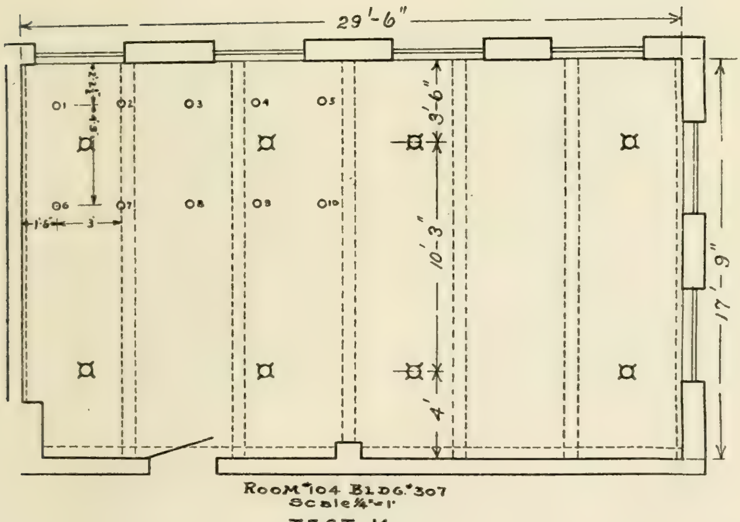
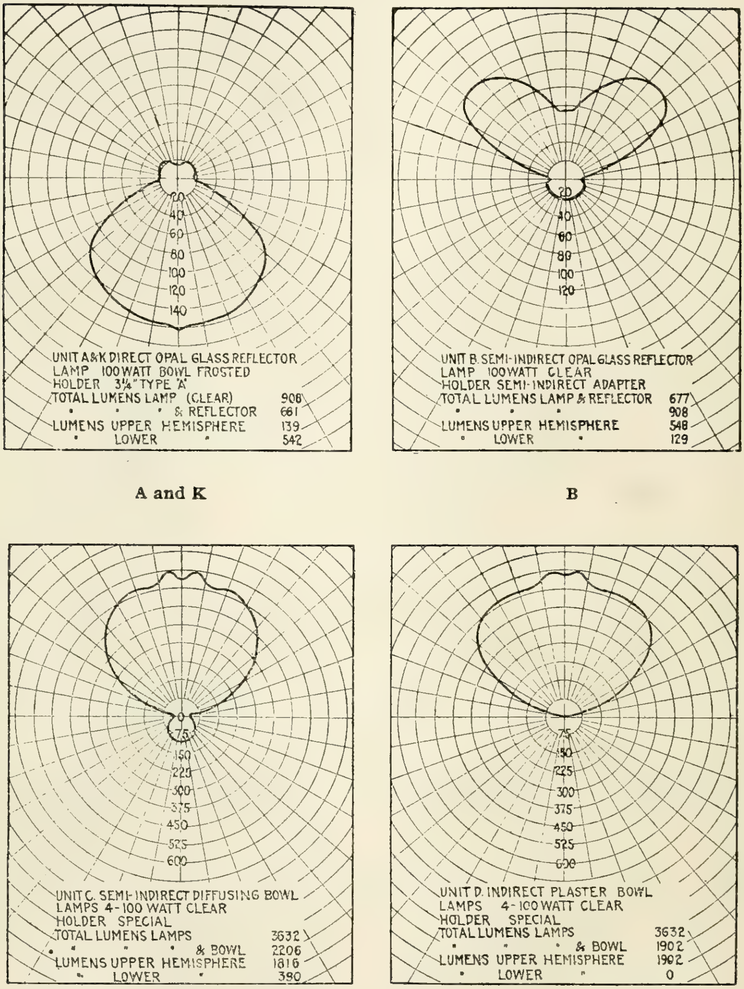

29'-6"
3'-6"
10'-3"
4'
17'-9"
ROOM #104 BLDG #307
Scale 1/4" = 1'
TEST K.

Fig. 4.

very simple and convenient method and also because the values so given furnish, it is believed, a better conception of the magnitudes than such units as candle-power per unit of area.



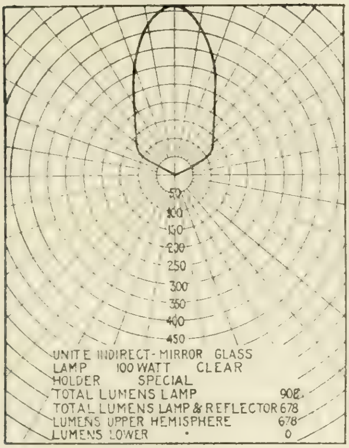
A and K B

C D

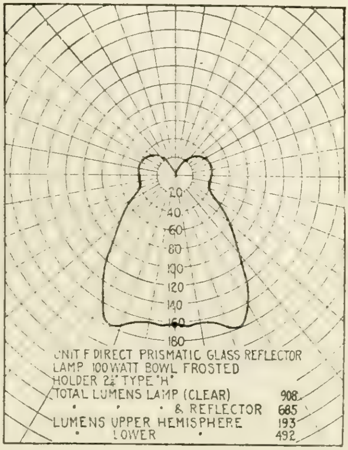
Fig. 5.

The data would be incomplete without including values showing the reflecting ability of the walls and ceiling. These reflec-

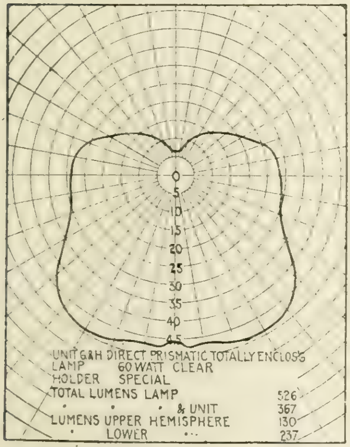
tion characteristics are also given relative to white blotting paper, that is the ratio of brightness of the surface in question to that



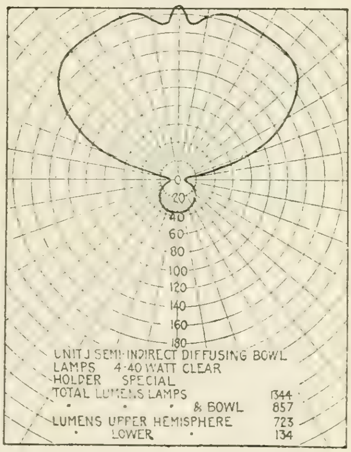
E



F



G, H and I



J

Fig. 6.

of white blotting paper in the same position and under constant and diffused light conditions.

The various systems employed in these standard offices are:

(A) Four direct, opal glass units fitted with bowl-frosted tungsten-filament lamps.

(B) Same as A except that reflectors are inverted and clear lamps used.

(C) One semi-indirect bowl with clear lamps in central outlet.

(D) One indirect plaster bowl with clear lamps in central outlet.

(E) Four mirrored glass indirect units with clear lamps.

(F) Four direct prismatic glass, intensive, with bowl-frosted lamps.

A single unit of each system is shown in Fig. 7.

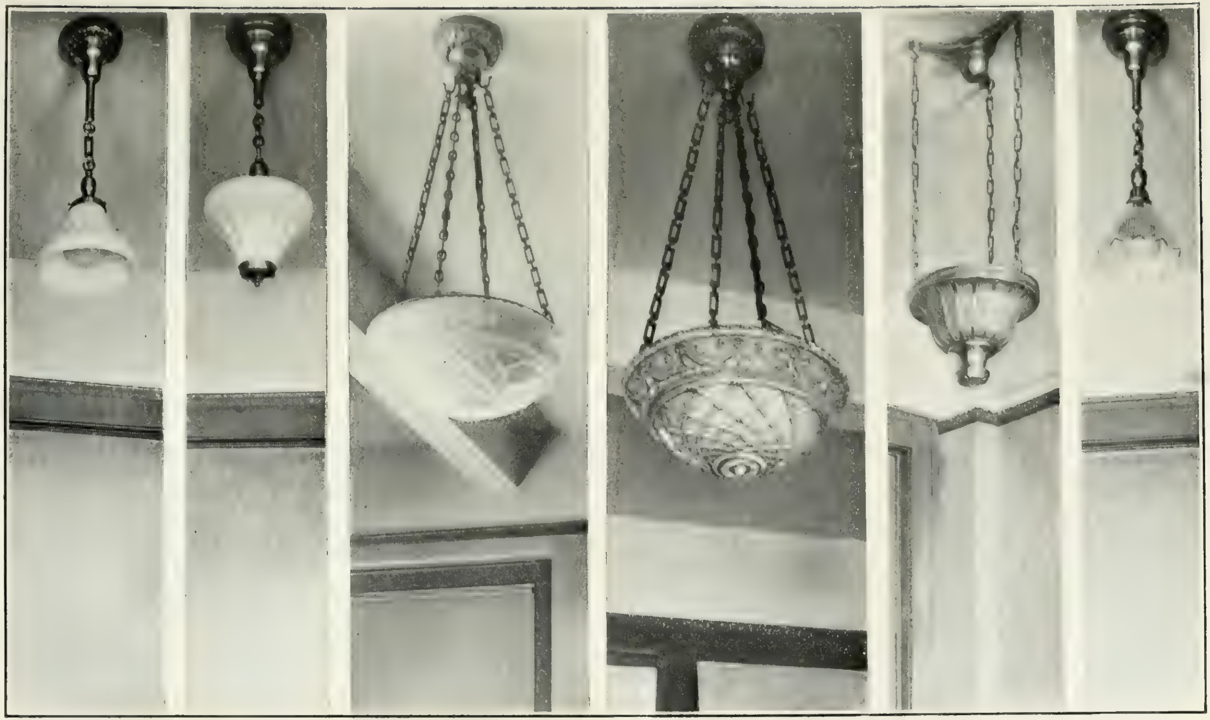
System A is the one generally adopted throughout the offices. The others are used in places where the requirements are special or where special consideration was given to the individual tastes of the occupant.

In the tests A-F lamps of equal luminous output were used so that comparisons show the results obtainable with the different systems with the same amount of light generated at the lamps. It is hardly necessary to state that the same wattage is not to be recommended; however, it was thought best for purposes of comparison to make tests on this basis. Reflectors in all cases were of the correct size for the wattage of lamps used, except that in the mirrored glass reflectors it was necessary to use an extension in order to insure the proper lamp position.

A summary of the results of tests A-F, as outlined above, is given in Tables 1 and 2.

Before comparing these systems with one another and with the efficiency figures in other installations, the exact conditions as regards spacing of outlets and character of walls and ceiling surface should be borne in mind. The walls are finished with a greenish-grey paint which reflects 53 per cent. as much tungsten-filament light as does white blotting paper. The white blotting paper used in all these tests showed on measurement by the Nutting* reflectometer method, a coefficient of reflection of 77 per cent. The walls, therefore, absorb 59 per cent. The ceilings

* Illuminating Engineering Society Transactions, Oct., 1912.



A B C D E F

Fig. 7.

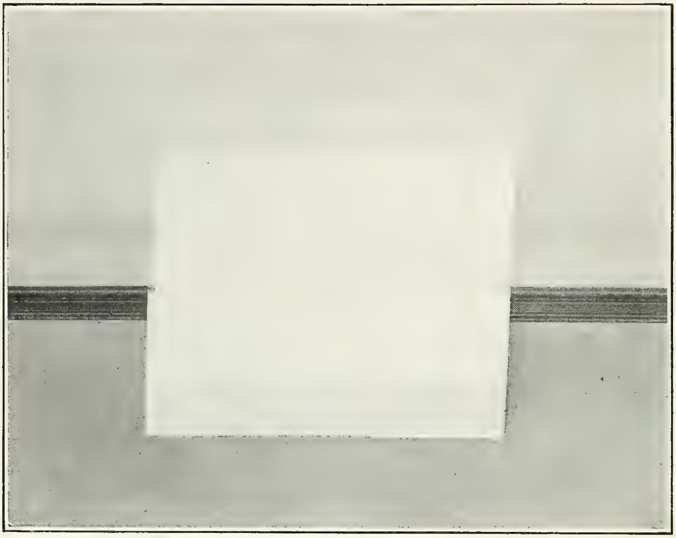


Fig. 8.

Fig. 10.

reflect 76 per cent. as compared with the blotting paper, and, therefore, absorb 41 per cent. of the light falling upon them. Fig. 8 shows a photograph which is intended to give an idea as to the relative brightness of ceiling and walls with respect to blotting paper.

TABLE 1.—INTENSITY DISTRIBUTION.

Description	Test	Illumination foot-candles on 30-inch plane: Average	Maximum	Minimum	Efficiency: Lumens per watt	Per cent. utilization efficiency
Direct, 4 units, opal glass, bowl-frosted lamps	A	4.58	5.54	3.89	2.95	32.5
Semi-indirect, 4 units, opal glass clear lamps	B	2.69	3.01	2.32	1.73	19.0
Semi-indirect, 1 unit, diffusing bowl, clear lamps	C	3.19	5.63	1.75	2.05	22.6
Indirect, 1 unit, plaster bowl, clear lamps	D	2.39	3.66	1.42	1.54	17.0
Indirect, 4 units, mirrored glass, clear lamps	E	2.65	3.04	2.20	1.70	18.7
Direct, 4 units, prismatic, bowl-frosted lamps	F	5.00	5.78	4.33	3.22	35.5

Room area—257.5 square feet and 4—100-watt lamps used in each test.

Ceiling height, 11 ft., 10 in. Height of unit above floor, Tests A, B and F, 10 ft., 6 in.; Tests C and D, 9 ft., 5 in.; Test E, 9 ft., 9 in.

TABLE 2.—SURFACE BRIGHTNESS DISTRIBUTION.

Description	Test	Surface brightness foot-candles equivalent to white blotting paper: Ceiling: Maximum	Ceiling: Minimum	Walls: Maximum	Walls: Minimum
Direct, 4 units, opal glass, bowl-frosted lamps	A	5.23a†	0.663b	6.03e	0.846f
Semi-indirect, 4 units, opal glass, clear lamps	B	1.95a	0.561b	2.13e	0.477f
Semi-indirect, 1 unit, diffusing bowl, clear lamps	C	60.3a	0.768d	1.83e	0.593f
Indirect, 1 unit plaster bowl, clear lamps	D	65.1c	0.280d	1.32e	0.263f
Indirect, 4 units, mirrored glass, clear lamps	E	60.2a	1.040b	2.52e	0.461f
Direct, 4 units, prismatic, bowl-frosted lamps	F	3.59a	0.995b	2.67e	0.782f

† See Fig. 9.

It is possible with the best white paint to obtain a coefficient of reflection as high as 85 per cent. Measurements on new white finished plaster surfaces showed coefficient of reflection as high as 92 per cent. Therefore, with the very best possible conditions, as regards ceiling, the illumination of the indirect systems could be raised more than 50 per cent. The semi-indirect systems could, of course, be made to show nearly as great an increase if the best possible ceiling surface were used.

Table 3 is a summary of reflection data for all tests.

TABLE 3.

	Reflection coefficient, per cent.	
Surface	Relative to white blotting paper as obtained by brightness readings	Absolute
White blotting paper	100	77
Walls in standard offices	53	41
Ceilings in standard offices	76	59
New factory white paint, worst	90	69
New factory white paint, best	110	85
New white finish plaster	120	92

At first thought it might be expected that some of the efficiencies would come higher, but considering the spacing of the outlets, shown in plan in Figs. 1-4, and bearing in mind the reflecting power of the walls and ceiling, one will see that in all the systems tested a large part of the light is necessarily lost by absorption of the walls. The lighting of rooms of a character similar to those tested involves not only the illumination of the working plane, but many other considerations such as the lighting of the walls, the elimination of dense shadows on the desks, etc. Utilization efficiencies given apply strictly only to this one size room with the same character of walls and ceiling. They are not representative of what may be obtained with larger spaces, an example of which appears later in the paper. However the size of the room and the finish of walls and ceiling represent a fair average of office buildings in general.

From Table 1 it may be seen that the four 100-watt direct prismatic units gave an average illumination of 5 foot-candles, which is higher than for any of the others. Since the wattage in each test was the same, the prismatic units gave also a higher efficiency. Table 4 shows the wattage which would have to be used to obtain the same quantity of light on the 30-inch plane.

TABLE 4.

Description	Test	Wattage necessary to produce an intensity of 5 foot-candles
Direct, 4 units, opal glass, bowl-frosted lamps	A	109
Semi-indirect, 4 units, opal glass, clear lamps	B	186
Semi-indirect, 1 unit, diffusing bowl, clear lamps	C	157
Indirect, 1 unit, plaster bowl, clear lamps	D	209
Indirect, 4 units, mirrored glass, clear lamps	E	189
Direct, 4 units, prismatic, bowl-frosted lamps	F	100

The differences in the direct, semi-direct and indirect systems of lighting would, of course, be decreased if the ceiling were of a high coefficient of reflection. Even though the coefficient of reflection of the ceiling is only 59 per cent., it has been termed a good white ceiling by many observers, and so perhaps does not differ greatly from the average ceiling used in semi-indirect and indirect systems.

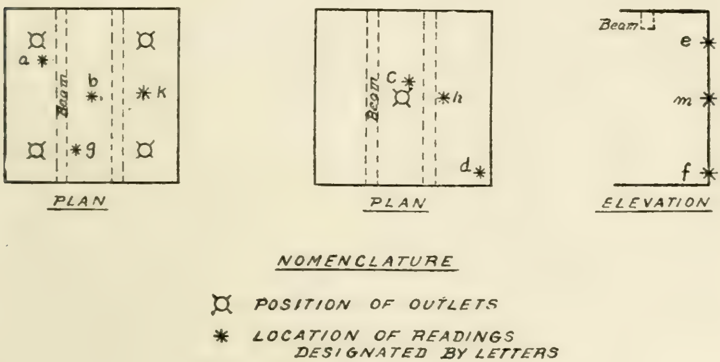


Fig. 9.

In comparing a central single unit system with the 4-outlet system, one should bear in mind that the single unit throws less light on the walls and, therefore, should give a higher average intensity on the 30-inch plane, everything else being equal.

Some interesting comparisons of uniformity of illumination can be made. The ratios of maximum to minimum values are remarkably similar for all systems with the same arrangement of outlets.

The brightness figures of Table 2 are of interest because they furnish some idea of the contrast presented to the eye. Fig. 9

TABLE 5.—INTENSITY DISTRIBUTION.

Description	Test	No. units	Area per unit sq. ft.	Wattage per unit	Illumination foot-candles on 30-inch plane			Efficiency	
					Average	Maximum	Minimum	Lumens per watt	Per cent. utilization efficiency
Direct, prismatic, totally enclosed, dirty, clear lamps, in corridor	G	Single row	102.3	1/60	1.14	1.47	0.90	1.94	22.2
Direct, prismatic, totally enclosed, clean, clear lamps, in corridor	H	Single row	102.3	1/60	1.27	1.63	1.02	2.17	24.7
Direct, prismatic, totally enclosed, clean, clear lamps, in corridor, alternate units turned on	I	Single row	204.6	1/60	0.647	1.23	0.280	2.21	25.2
Semi-indirect, diffusing bowl, clear lamps	J	4	77.5	4/40	3.54	4.08	2.71	1.72	20.5
Direct, opal glass, bowl-frosted lamps	K	8	65.5	1/100	5.34	6.18	4.66	3.50	38.6
Direct, prismatic, clear lamps, wide spacing in basement	L	4	186.2	1/150	4.54	5.93	2.73	5.63	59.1
Direct, enameled steel bowl	M	2 rows staggered	144.0	1/100	3.04	3.47	2.11	4.38	48.2

Ceiling height, Tests G, H, I, J, K—11 ft., 10 in.; Tests L and M—12 ft., 8 in. Height of units above floor, Tests G, H and I—10 ft., 6 in.; Tests J—9 ft., 5 in.; Test K—10 ft., 6 in.; Test L—11 ft., 5 in.; Test M—11 ft., 11 in.

is a key to the positions where the readings were taken. The brightest spot on the walls was one where the most specular reflection took place. Here again many interesting comparisons are possible. It is seen that all the semi-indirect and indirect methods show very high ceiling contrasts, but low wall contrasts. On the other hand, the direct units show low ceiling contrasts, but higher wall contrasts. This is, of course, as would be expected, but perhaps the actual magnitude of the differences will be of interest.

The results of other tests besides those in the typical office are given in Tables 5 and 6.

TABLE 6.—SURFACE BRIGHTNESS DISTRIBUTION.

Description	Test	Surface brightness foot-candles equivalent to white blotting paper. Ceiling Maximum	Ceiling Minimum	Walls Maximum	Walls Minimum
Direct, prismatic, totally enclosed, clean, clear lamps, in corridor	H	3.22a	0.272b	1.69e	0.174f
Semi-indirect, diffusing bowl, clear lamps......	J	26.0a	2.27b	2.16e	0.583f
Direct, opal glass, bowl-frosted lamps..........	K	5.23a	0.663b	6.03e	0.846f
Direct, prismatic clear lamps, wide spacing in basement	L	6.41a	1.18g	4.94e	2.12f
Direct, enameled steel bowl.................	M	0.454k	0.333k	1.79e	0.336m

Considering the first, Test J. the result of placing four of the semi-indirect bowls of Test C in a larger room is seen. The wattage per unit is cut down from 400 to 160, thereby reducing the brilliancy of the unit and ceiling. The utilization efficiency is not as good because of the wide spacing resulting in more wall illumination, but the uniformity is much better, the ratio of maximum to minimum illumination being 3.22 and 1.51 in the two cases.

A corridor is lighted by a single row of totally enclosed prismatic units containing 60-watt lamps. Readings were taken in a fairly typical section with all lamps lighted and the units in a somewhat dusty condition after 8 weeks of use through a period when building construction was being completed. The lamps and

glassware were then cleaned and tests made with all lamps and half of the lamps burning. The narrow hall cannot be lighted with the same efficiency obtained in larger areas, and in this case light thrown upon the walls was either largely absorbed by the dark finish or transmitted by the rough glass which forms a large portion of the wall area. It is therefore not surprising that the light on the usual reference plane does not exceed 25 per cent. of that generated. The uniformity with all lights on is even better than would be considered necessary as shown by a ratio of maximum to minimum illumination of 1.6. With half of the units in service this ratio is 4.4.

The dust accumulation of 8 weeks proved to reduce the illumination about 11 per cent. at all points. This serves as another example of the necessity of cleaning lighting units. The 8-week period was probably equivalent to twice that for normal operation of the building.

The next series of tests are all on direct systems utilizing the three types of reflectors in very general use in office buildings,—prismatic glass, opal glass and enameled steel.

The first test may be taken as indicative of what is to be obtained under favorable conditions with standard equipment of prismatic reflectors. The ceiling and upper part of the walls are finished in factory white which from tests proved to have a high reflecting power. The value of 5.63 lumens-per-watt (uncorrected for photometer test plate error) with 150-watt lamps speaks for itself and is obtained at a utilization efficiency of 59 per cent. If increased 12 per cent. for test plate error, the utilization efficiency becomes 66 per cent. The spacing would be called fairly wide and the room large. It is seen that the uniformity is represented by the maximum-to-minimum ratio of 2.17.

Direct lighting opal glass units were installed in 8 outlets in a room of the same width and characteristic finish as the offices, but having about twice the area. Compared with the prismatic installation just mentioned, the uniformity is better, but the efficiency not so good. By comparing with Test A. which is similar in every way except in size of room, something of the effect of wall absorption in small rooms may be seen. By doubling one dimension of the room the utilization efficiency is increased from 32.5 to 38.6 per cent.

The test with 100-watt enameled steel units took place in the machine room where objects are dark, but ceiling and walls light, as is fairly typical of certain service spaces in office buildings, and also in factories, where such lighting equipment is employed.

The arrangement of outlets consists of two rows with units staggered. The uniformity index is good (1.64) and the utilization efficiency (48 per cent.) is representative of what may be expected with this form of opaque reflector, under conditions where a small number of units contribute to the lighting of any one spot. The ceiling, since it receives all of its light indirectly, is very uniformly illuminated.

It was not the intention to attempt to draw any sweeping conclusions from these tests, but something should be said of the efficacy of the two methods of locating the outlets. The single office spaces usually have desks and cases placed next to walls. Many have tables in the middle. The arrangement of furniture in one of the rooms which seems to be fairly typical of office buildings is shown in the photograph of Fig. 10.

The central outlet system of lighting, either direct or indirect is not considered entirely successful where the desks are placed next to the walls as in Fig. 10. In the conference rooms where the work is done around a large table in the middle, either method is satisfactory.

The 4-outlet systems could have been designed for a higher utilization efficiency by placing the outlets nearer the middle of the rooms, but another glance at Fig. 10 will show that the best position of the fixture with respect to the natural desk position would have been sacrificed by placing the outlets nearer together.

The authors wish to express their thanks to Mr. E. B. Rowe for valuable suggestions for the design of the systems described in this paper, to Mr. Luckiesh for verifying the reflection co-efficient measurements, and to Mr. H. T. Spaulding and others for help in obtaining the photometric readings.

DISCUSSION

Mr. E. B. Rowe: There are, I think, a number of rather important and striking features which Mr. Edwards has brought out, and they are largely a result of the extreme care with which he entered into the preparation of the paper. For instance, the measurements of the intrinsic brightness are, I think, helpful; and the same may be said of the data which he gives on the reflection coefficients. Any one going into the building from which the measurements were obtained would be impressed with the whiteness and probable high reflection coefficient of the ceilings. I know a number of people who were asked what they thought the ceiling reflection coefficient was, and everyone placed it considerably higher than it proved to be, showing that we may be little off in our calculations in designing a system which depends on the reflection coefficient.

Another feature of this installation which appealed to me was the low reflection coefficient of the walls. The brightness of the wall, I think, is very good for office lighting, and the color selected is a considerable improvement over green, or a buff.

The tests on some of the glassware show considerable attainment in design, in that the utilization is pretty good for a diffusing unit. The intensities are quite low on the horizontal with both the small units and the so-called Nela bowl; and in a room of larger dimensions this would tend toward both a higher physical efficiency and a better visual efficiency.

The question of indirect lighting is receiving considerable discussion from the standpoint of how much transmitted light is permissible, and attempts are being made to secure an approximation to a figure which seems to be accepted by a number of competent illuminating engineers—about 15 per cent. downward transmitted light. It happens, I think, that the Nela bowls having the 4 100-watt and 4 40-watt combinations transmit from 15 to 20 per cent. The brightness of these bowls is quite low, so that it is possible, as was shown in that glassware, to obtain with a single-piece glass bowl an acceptably low transmission.

Another feature which impressed me was the small loss in the light from the corridor units during the eight weeks of deterioration due to accumulating dust and dirt. During that period

(while the interior finishing was being completed) the deterioration conditions were so severe that the loss was a great deal higher than would ordinarily be the case; and the use of totally enclosing glassware, it seems to me, might be favored in a great many localities where the conditions are likely to result in a very rapid and a relatively high deterioration of light from other kinds of units.

Mr. Edwards' paper seems to me to indicate no considerable advantage—in fact no apparent advantage—for a single semi-indirect or totally indirect unit in the center of an office. As to the distributed unit system, it has been in use for a great many years and has always proven quite satisfactory, so that from the deterioration standpoint and in the light of the facts presented in the paper, the distributed unit systems would still seem to be very acceptable indeed for general office lighting.

MR. S. G. HIBBEN: It seems worth while to mention the fact that it is becoming more and more realized how much a good example of lighting installation may do to advance the cause of good lighting; and I think it is noteworthy in this instance that more thought has been given than has previously been the case in buildings of lighting companies. It has been my experience that usually people who should pay most attention to their lighting are perhaps so busy advising other people that they do not follow the precepts they preach.

I might call attention, with profit, to the deterioration tests. I believe, considering the prismatic satin-finish, that the utilization percentage of efficiency with the dirty glassware amounted to about 22.2, which rose to a utilization factor of approximately 24.7, in which there was about an 8 or 10 per cent. increase in the use of the light simply due to the cleaning of the enclosing globe. It seems worth while to call attention to the fact that the average expense for cleaning a unit amounts to something like three cents a month. Taking a unit of normal size it would be washed once and dusted once each month. That would amount to something like 35 cents a year for cleaning a 100-watt unit. The average annual cost of burning a 100-watt lamp at 10 cents per k. w. is about $12.00. If a 10 or an 8 per cent. gain could be made by cleaning, that would mean about $1.20 gain per year due to

cleaning; and if cleaning costs amounted to only 35 cents or 40 cents a year, it is very evident that careful cleaning is a rather important factor.

MR. H. KIRSCHBERG: I am very much interested in this paper. It shows a great deal of preparation. I am rather inclined to sound a word of warning to those who would apply the data given in the paper to any particular case. The conditions, as has been pointed out a great many times before, must always be taken into consideration. For example, the conditions found in railroad offices are, in very many cases, entirely different from those found in other office buildings—possibly different from those found in the offices described. One office in particular in the Pennsylvania Railroad offices at Altoona is approximately 80 ft. long, 20 ft. wide, and no particular attention to the relative positions of desks and windows was given when the lights were placed. In addition to that the walls are taken up with filing cabinets, typewriter desks, adding machines and other equipment. Both black and red inks are used. The bug-bear of the entire installation was the use of the ordinary copying pencil. When it comes to designing a lighting installation for an office in which a copying pencil is used the problem of efficiency is of minor importance. The reflection from the surface of the writing with that pencil is sufficient to produce such a high degree of occular trouble as to put a man out of commission for a part of his working time. Another office used in railroad practise in which this problem enters to a much greater degree is that of a ticket receiver. He not only works all day but the office is also open at night for the work of his partner. Tickets are received during the day and night, and all work is done with a copying pencil. The use of red ink also complicates the problem. Special consideration must be given to the visual efficiency of illumination.

MR. C. J. MUNDO: I would like to ask Mr. Edwards how he describes the color used on the walls of these offices.

MR. E. J. EDWARDS (In reply): I did not note any questions to be answered in Mr. Rowe's very interesting comments. Mr. Rowe has been in close touch with the work of this paper from the beginning and his assistance both in the design of the installation and in his comments of this evening are greatly appreciated by the authors.

Mr. Hibben brought up the question of the character of the surface of this type of indirect unit. He was right in supposing that a plaster surface is the only reflecting surface placed within the bowl. The surface of the plaster was scraped so that the reflecting surface was as good as could be obtained. I should say in this connection that a plaster surface is not such a bad reflecting surface. It is very efficient and it differs from a more permanent surface such as, say a mirrored glass or a porcelain enameled surface, mainly in that it gives a wider distribution on the ceiling. It cannot be cleaned and restored to its original efficiency; otherwise it is all right. The wide angle of distribution is no disadvantage to the unit. Even with the broader distribution with this plaster unit the light is practically all directed to the ceiling—very little of it goes directly from the unit to the walls.

For the glass semi-indirect unit the lumens in the upper hemisphere numbered 1,816, and in the lower hemisphere 390; or a total of 2,206. With the plaster bowl a total of 1,902 lumens was obtained, all in the upper hemisphere. When the surface is clean, as in this test, a plaster bowl is a fair indirect unit. Only two of these units were used in the installation in question.

I think everything that Mr. Hibben said in regard to the necessity of cleaning units is indeed well taken. I do not believe very many people question the fact that it is cheaper to clean units than to neglect them and have light wasted by dirty units.

In regard to Mr. Kirschberg's remarks, I wish to emphasize that figures of the sort given in this paper should be used with great care, because conditions that must be met are extremely different in different cases, as will be noted from the remarks made to-night comparing the general arrangement of furniture in architectural offices, with the arrangement of fixtures in the type of office of which Mr. Kirschberg speaks, where the filing cases are placed around the room with a table or desk in the middle of the room. Of course the smaller outlet system can very well be considered for a space of this kind.

Also, in connection with applying efficiency figures obtained in a particular installation, I would emphasize that I do not pretend to say that these figures should be generally used. We have tried in this paper to outline the conditions as carefully as pos-

sible, giving even the absolute coefficients of reflection of walls and ceilings and the exact location of outlets. The exact test conditions have been stated so that the given figures may always properly be considered by one reviewing the records of the tests.

It was indeed surprising to find that the coefficient of reflection of the ceilings was so low. A number of people who are accustomed to judge such things were asked what they thought the coefficient of the ceiling was. Without exception they said they thought it was about as good as could be obtained. While the ceiling in this particular case has a surprisingly low coefficient of reflection as judged from its appearance, it is probably as good as will be found in the average installation where it is intended to make the ceiling reflection as good as possible. The better the coefficient of reflection of the ceiling the brighter it is, of course, during daylight hours. In some cases where the ceiling comes into the ordinary range of vision it may be an advantage not to make the ceiling so white where the direct systems are used, in order to keep down the brightness during the daylight hours. In the semi-indirect and in the indirect systems, one depends, of course, entirely on the reflecting power of the ceiling. If the ceilings tested had been newly finished (white plastered) the efficiency of both the indirect systems and the semi-indirect systems would have been increased about 50 per cent. This would represent the best possible condition. Of course this could not be obtained under average conditions over a period of time.

Certainly the utilization efficiency, the physical efficiency, is only one of several important features of good lighting. I agree with Mr. Kirschberg that the efficiency figures should not be taken as a measure of the over-all desirability of lighting installations.

As regards Mr. Mundo's question as to how the color of the walls might be described, it has been given in the typewritten form of the paper as greenish-gray. I don't know that that really expresses it; but it is the impression it gives me. It is a more efficient reflector for tungsten light than a shade of blue would be. The contrast between the walls and the ceiling appears very much higher in daylight than under artificial light.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 2, 1914

PART II

Miscellaneous Notes

Council Notes.

A regular meeting of the Council was held in the general offices of the Society, 29 West 39th Street, New York, February 19, 1914. Present were: C. O. Bond, president; Joseph D. Israel, general secretary; V. R. Lansingh, W. J. Serrill, Ward Harrison, Alten S. Miller, Preston S. Millar, C. J. Russell, L. B. Marks, and G. H. Stickney. Dr. H. E. Ives, chairman of the Research Committee, was present upon invitation.

President Bond called the meeting to order at 2:25 P. M.

The minutes of the January meeting were amended slightly and adopted.

Upon recommendation of the Finance Committee, it was voted to authorize the payment of the January vouchers, Nos. 1586 to 1633, aggregating $2,148.94.

A report was received from a special committee, which had been appointed at the January meeting, to consider certain phases of the financial policy of the society. The report favored increasing the revenue from sustaining members, maintaining the revenue from advertising, and increasing substantially the individual membership of the society so as to in turn increase the income from this source, and urged that an effort be made by the Finance Committee to keep the expenses of the society for any year within 90 or 95 per cent. of the total estimated income. It was also recommended that, provided the income warrants it, a sum not in excess of 5 per cent. of the estimated income be set aside for a reserve fund until the maximum of $5,000 has been accumulated.

Mr. Israel presented a report on the membership for the first five months of the present fiscal year. The report showed a net increase of 47 members.

Dr. H. E. Ives presented a written report of the work and plans of his Committee on Research. An outline of the report follows:

The meetings of the Committee, which will be monthly, will each be devoted to the discussion of a selected topic. A report of the Committee's deliberations, containing its suggestions for future research, criticisms of previous work, and information of use to research men, such as bibliographies, etc., will be made to the Council. It is suggested that these reports be printed in full in the TRANSACTIONS, and that at the end of the Society year a reprint of the whole body of reports be sent to all the chief educational institutions and laboratories here and abroad. The Committee does not itself undertake to do rearch, but being a committee of "researchers" a channel is automatically provided for the voluntary carrying out of ideas brought forward at the meetings. It is expected that the meetings, with the discussions between men interested in similar problems, will be stimulating to a high degree and will ultimately show their effect in the work done by the members, or at their suggestion. This will, in fact, be the principal object of the committee—to bring together active workers in various fields for their mutual profit. The matter of publicity and of immediate assistance to the Society will be taken care of by the published reports, and by the Committee holding itself always ready to consider as routine business any questions put to it by the other Committees of the Society.

The subject discussed at the first meeting of the Committee was entitled: "Harmful Radiations and the Protection of the Eyes Therefrom." A report of this meeting, together with an extensive bibliography on the subject will be published in the next issue of the TRANSACTIONS.

A written report proposing certain changes pertaining to the issuance of the TRANSACTIONS was received from the Committee on Editing and Publication. The TRANSACTIONS will hereafter be published at regular intervals of 40 days, instead of monthly with no issues during the months of July, August and September. No change will be made in the number of issues, nine, published in a year.

It was voted to suggest to the Committee on Reciprocal Relations a consideration of a joint meeting with the

American Institute of Electrical Engineers during the annual convention of the latter organization in June, 1914. It was proposed that the I. E. S. might contribute up to $40.00 to the expenses for arranging such a meeting. It was understood, however, that such an appropriation would be subject to the approval of the Finance Committee.

A question arose as to the advisability of the sections of the society holding joint meetings with the local sections of other societies. A number of the members of the Council were of the opinion that this matter was being overdone and the society was losing its identity by such action; other members were of the opinion that these meetings stimulate interest in the society and promote closer relations with other societies, thereby advertising the work of the society. It was voted to refer this question to the Committee on Section Development. The committee will in turn invite criticisms of the question from the several section boards of management.

Informal reports on progress were made by Mr. Joseph D. Israel, chairman of the Section Development Committee, and Mr. L. B. Marks, chairman of the Lighting Legislation Committee.

A written report pertaining to designating lighting systems and glassware was received from the Committee on Nomenclature and Standards. It was voted to refer this report back to the committee, with the request for further investigation and amplification.

Mr. Israel reported on behalf of the Progress Committee that the committee is not in a position to undertake the preparation of abstracts of articles and publications on illumination for printing in the TRANSACTIONS. This question had been referred to the committee some time previously. The committee, however, has stated its willingness to submit for publication in each issue of the TRANSACTIONS a list of the titles of current articles and publications dealing with the subject of illuminating engineering.

Consideration was given to a request for a lighting exhibit similar to the one installed at the American Museum of Safety, to be displayed at the Cleveland Electrical Show. The question was referred to Mr. Ward Harrison, with a request that he report at the next Council Meeting.

Mr. G. H. Stickney, chairman of the Lighting Exhibit Committee, presented a written report, describing a series of booths illustrating the various principles of illumination, which had been displayed at the International Exhibition of Safety and Sanitation in the Grand Central Palace in December, 1913. The exhibit was awarded a grand prize and diploma. It has been permanently installed in the American Museum of Safety, 29 W. 39th Street, New York, N. Y.

The expenses of the committee were estimated at $66.00 in excess of the fund collected for the exhibit. It was voted to pay this excess expense upon approval of the Finance Committee.

A written report of progress from the Papers Committee was read.

It was voted to hold the 1914 Convention in Cleveland during the week beginning September 21.

It was suggested that the Committee on Reciprocal Relations arrange to have a delegate from the I. E. S. present a paper at the convention of the American Association of Iron and Steel Electrical Engineers, which is to be held in Cleveland in September.

Mr. G. H. Stickney, chairman of the

Committee on Popular Lectures, presented a written report on the progress of the work of the several sub-committees, namely, store, residence, office and industrial lighting.

Verbal reports on section activities were received from the following vice-presidents: Mr. W. J. Serrill, Philadelphia; Mr. G. H. Stickney, New York; and Mr. Ward Harrison, Pittsburgh. Mr. J. W. Cowles, vice-president of the New England Section, reported in a telegram that a meeting of his section was being arranged for the latter part of February.

The following committee appointments were approved:

Membership Committee: H. E. Grant, R. H. Manahan, F. A. Osborn, Harold Kirschberg, G. E. Williamson, W. R. Collier, A. L. Abbott, J. J. Burns, S. L. E. Rose, A. L. Wilson, and W. S. Kilmer.

Committee on Reciprocal Relations: Frank E. Wallis, C. J. Mundo, and Stephen A. Thomas.

Committee on Papers: R. B. Hussey.

The names of N. H. Boynton and C. W. Bettcher were added to the committee—as yet unnamed—which is to consider the proposition of circulating throughout the country various booths illustrating the use and misuse of light.

Dr. Louis Bell was appointed a representative of the society to the United States National Committee of the International Commission on Illumination. The other representatives are Dr. E. P. Hyde and Mr. L. B. Marks.

Mr. Marks was reappointed a delegate to the International Gas Congress. A suggestion from Mr. Marks that $25.00 be subscribed toward the expenses of the International Gas Congress was referred to the Finance Committee.

Mr. Preston S. Millar was appointed a committee of one to determine the cost of a lighting exhibit for display at the convention of the Ethical Culture Society, which is to be held in New York in April, 1914.

The meeting adjourned at 6:25 P. M.

Section Activities

CHICAGO SECTION

A meeting of the Chicago Section was held February 11, 1914, at the plant of Sears, Roebuck & Company, Chicago, Ill. Mr. S. E. Church presented a paper on the lighting of the buildings of the latter company. The members in attendance inspected the various parts of the building and the lighting equipment used. One hundred and three members and guests were present.

NEW ENGLAND SECTION

The New England Section has planned to hold a meeting early in April. The subject for discussion will probably be "Gas Lighting."

NEW YORK SECTION

The New York Section held a joint meeting with the Municipal Art Society in the United Engineering Societies Building, 29 West 39th Street, February 11. The papers presented were: "Some Notes on Present Day Street Lighting" by Mr. Arthur Williams, "The High Intensity Lighting of European Cities Compared with New York" by Mr. C. F. Lacombe. One hundred members and guests attended the meeting. An informal dinner which preceded the meeting was attended by 38 members and guests.

The April meeting is to be a joint meeting with the American Museum of Safety. The following papers are

scheduled: "Illumination as a Factor of Safety in Industrial Plants" by Mr. R. E. Simpson, of the Travellers Insurance Company; "Railroad Yard Lighting from the Standpoint of Safety" by Mr. J. W. Ensign, illuminating engineer, New York Central Railroad; "Glasses for the Protection of Eyes from Ultraviolet Rays" by Mr. M. Luckiesh, assistant physicist of the National Electric Lamp Association.

PHILADELPHIA SECTION

The Philadelphia Section held a joint meeting with Franklin Institute in the auditorium of the Institute, February 18. Dr. Herbert E. Ives presented a paper entitled "Artificial Daylight." One hundred and fifty members of both organizations were present. An informal dinner at the Engineers Club preceded the meeting.

The following program has been arranged for the rest of the present season:

FRIDAY, MARCH 20.

"Lighting and Signalling Systems of Subways."
By Mr. F. D. Bartlett.
"The Sun—The Master Lamp."
By Prof. James Barnes.

THURSDAY, APRIL 9.

Joint Meeting with Franklin Institute.
"Recent Developments in the Art of Illumination."
By Mr. Preston S. Millar.

FRIDAY, APRIL 17.

"The Structure of the Normal Eye and its Ability to Protect Itself Against Ordinary Light."
By Dr. Wendell Reber.
"Glassware for Illumination and Other Purposes."
By Mr. James Gillinder.

FRIDAY, MAY 15.

Mass Meeting of all the Engineering Societies of Philadelphia and Vicinity.
Special Program to be arranged and to include an address on
"The Relation of Engineers to the Progress of Civilization."
By Dr. Chas. Proteus Steinmetz.

PITTSBURGH SECTION

The Pittsburgh Section held a meeting in the auditorium of the Engineers Society of Western Pennsylvania, February 14. Messrs. A. C. Cotton and Harold Kirschberg presented a paper entitled "Lighting of Railroad Yards." Sixty-three members and guests were present.

The following program has been arranged for the balance of the present season:

MARCH 13TH.

"Modern Gas Lighting" by S. B. Stewart, Contract Agent for Consolidated Gas Company, Pittsburgh, Pa. This meeting will be devoted to the discussion of gas arcs as applied to modern illuminating systems. A number of prominent manufacturers and operators will be present and take part in the discussion.

APRIL 17TH.

"The Development of Flame Carbon Arc Lamps" by C. E. Stephens, Westinghouse Electric & Mfg. Company. The author will trace the growth and development of this popular form of illuminant from its inception down to the present time, showing how the difficulties first experienced have been overcome, and its application to various fields."

New Members.

The following twenty-nine applicants were elected members of the Society at a meeting of the Council held February 19, 1914:

AUTRIM, WM. D.
Assistant Engineer, Welsbach Company, Gloucester, N. J.

BARNES, WILL W.
Bayley & Sons, Inc., 105 Vanderveer Street, Brooklyn, N. Y.

BARNETT, T. T.
Salesman, Bryan Marsh Division of General Electric Company, 431 South Dearborn Street, Chicago, Ill.

CASSELL, D. H.
Manager, Ruboil Belting Company, 610 West Randolph Street, Chicago, Ill.

COFFEY, E. W.
Engineer, National X-Ray Reflector Company, 235 West Jackson Boulevard, Chicago, Ill.

DAILEY, E. J., JR.
Illuminating Engineer, Westinghouse Lamp Company, 1261 Broadway, New York, N. Y.

EDMUND, H. W.
Commercial Agent, Western United Gas & Electric Company, 36 Fox Street, Aurora, Ill.

EGAN, PAUL C.
Salesman, Macbeth-Evans Glass Company, 143 Madison Avenue, New York, N. Y.

GERNON, GEORGE H.
Salesman, Macbeth-Evans Glass Company, 143 Madison Avenue, New York, N. Y.

GRAVES, L. H.
Supervising Engineer, National X-Ray Reflector Company, 6 East 39th Street, New York, N. Y.

GRISWOLD, L. E.
Illuminating Engineer, Macbeth-Evans Glass Company, 808 Wabash Bldg., Pittsburgh, Pa.

HANSCOM, W. W.
Consulting Engineer, 848 Clayton Street, San Francisco, Cal.

HITCHCOCK, GEORGE G.
Professor of Physics, Pomona College, Claremont, Cal.

HUDSON, R. A.
Consulting Engineer, Hunter & Hudson, 729 Rialto Bldg., San Francisco, Cal.

KEGERREIS, ROY.
Instructor in Electrical Engineering, University of Pennsylvania, 448 South 43rd Street, Philadelphia, Pa.

LLOYD, WILLIAM F.
Power Salesman, The Philadelphia Electric Co., 1000 Chestnut Street, Philadelphia, Pa.

MASSON, CHARLES M.
Illuminating Engineer, Southern California Edison Company, 129 East 4th Street, Los Angeles, Cal.

MOHR, OTTO H.
President, Mohrlite Company, 253 Minna Street, San Francisco, Cal.

MORGAN, ARTHUR M.
Engineer's Assistant, Consolidated Gas Company, 124 East 15th Street, New York, N. Y.

MOSES, PAUL E.
Efficiency Engineer, Consolidated Gas Company, 4 Irving Place, New York, N. Y.

NIXON, JOHN A.
Manager, Macbeth-Evans Glass Company, 143 Madison Avenue, New York, N. Y.

OKIE, GEORGE M.
Salesman, Macbeth-Evans Glass Company, 143 Madison Avenue, New York, N. Y.

SILVERMAN, ALEXANDER.
Director of Dept. of Chemistry, University of Pittsburgh, Grant Boulevard, Pittsburgh, Pa.

SMITH, HOWARD R.
Public Service Electric Co., Bank and Broad Streets, Newark, N. J.

STEINHARTER, JOSEPH J.
Salesman, Laco-Philips Company, 131 Hudson Street, New York, N. Y.

TAYLOR, D. A.
Treasurer, H. Northwood Company, Wheeling, W. Va.

TOUT, T. ATKINS.
Manager, Cowtan & Sons, Ltd., London, England, 542 Fifth Avenue, New York, N. Y.

TRESIZE, JOHN M.
Illuminating Electrical Engineer, Government Post Office, London, England.

WEST, WM.
Gas Arc Lamp Maintenance, 812 John Street, Portsmouth, O.

Sustaining Membership.

At a meeting of the Council held February 19, 1914, Messrs. Henry L. Dougherty & Company, 50 Wall Street, New York, were elected a sustaining member of the Society.

1914 Convention of I. E. S.

The eighth annual convention of the Illuminating Engineering Society will be held in Cleveland, O., during the week of September 21, 1914. Mr. W. M. Skiff, of the National Electric Lamp Association, Cleveland, has been appointed Chairman of the General Convention Committee.

Change in Publication Dates of Transactions.

Beginning with the present issue the TRANSACTIONS will be published at regular intervals of forty days, instead of monthly with no issues in July, August, and September. The new method of publication will permit of the publication of number of papers more promptly than could be done under the old plan. The designation of issues by months has been discontinued; numbers only will be used. No. 3 will be published April 30; No. 4, June 10; No. 5, July 20, etc.

Index to Volume VIII.

The index to Volume VIII (1913) TRANSACTIONS of the I. E. S. will be mailed with No. 3 issue of the present volume, April 30, 1914.

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THE MEASUREMENT OF BRIGHTNESS AND ITS SIGNIFICANCE.

BY HERBERT E. IVES.

Synopsis: This paper emphasizes the importance of measuring surface brightness rather than illumination in cases where an adequate idea is to be rendered of the actual field of view of an observer. The eye is a small camera forming upon the retina a picture corresponding point for point with the outer world. According to well-known optical principles the brightness of the images thus formed is independent of the distance of the eye from the bright surface. The methods of measuring brightness are described in some detail. A brief discussion is given of the range of intrinsic brilliancies to be found in natural and artificial lighting systems.

INTRODUCTION.

Of late in illuminating engineering increased attention has been paid to the question of intrinsic brightness, not only the intrinsic brightness of light sources, but of all objects in the field of view. This is the logical outgrowth of a closer and closer study of the problems of lighting; for, in its last analysis, the task of the lighting engineer is to produce in the field of view a *distribution of brightness possessing certain desirable characteristics,* a matter more fully discussed below. The mere production of a certain illumination cannot guarantee a desirable brightness distribution, nor can a lighting installation be described, for purposes of scientific study, in terms of illumination.

A recent paper of the writer's before this Society,[1] in which measurements of surface brightness were used exclusively in describing the results of illumination experiments, brought out

[1] "Some Home Experiments in Illumination from Large Area Light Sources," TRANSACTIONS I. E. S., June, 1913.

the fact that neither the meaning of such measurements, nor the method of making them, is as generally understood as should be the case. For that reason it seemed well to gather together in brief form some information on the subject.

DEFINITION OF BRIGHTNESS.

Every visible surface is giving out light; in other words, it is a light source of definite and measurable candle-power. It has area, which too is measurable. To measure the candle-power per unit of area thus becomes a definite physical problem. This quantity expressed in consistent units, such as candle-power-per-square-centimeter, is defined as the *brightness* of the surface. The definition, as given by the Committee on Nomenclature and Standards of the I. E. S., is made complete by taking into account the fact that the area in question is the *apparent* area. This official definition is as follows:

> **Brightness. b. of an element of a luminous surface from a given position, is the luminous intensity per unit area of the surface projected on a plane perpendicular to the line of sight, and including only a surface of dimensions negligibly small in comparison with the distance to the observer. It is measured in candles per square centimeter of the projected area.**

THE MOST STRIKING CHARACTERISTIC OF BRIGHTNESS.

Perhaps the most striking characteristic of brightness, as distinguished from illumination, is that it does not change with the distance between the bright surface (real or virtual) and the observer. A bright surface is equally bright whether one views it from 1, 10 or 50 meters. This follows from the definition, for brightness is a physical characteristic of the light-giving surface, not of the observer's eye or position. The meaning of this with respect to the eye is important. The light flux entering the eye from any small surface varies inversely as the square of the distance from the surface to the eye. But likewise the solid angle subtended by the surface varies inversely as the square of the distance. Consequently the flux per unit area on the image upon the retina remains the same; in other words, the brightness of that image is constant. Remember that the eye is a camera; and it follows immediately that a measurement of the brightness of surfaces in the field of view is also a measure of the relative brightness of the corresponding parts of the image on the retina. As a consequence of this attribute of brightness, it may be meas-

ured from any position. While, for instance, an ordinary photometer placed in the center of a room can measure only the illumination at that point, a brightness measuring instrument can from that location survey the whole visible room—walls, floor and furniture. Perhaps the most accurate commonly understandable analogy to illumination and brightness measurements is furnished by the photographic camera. Let it first be used in the ordinary manner to take a picture of the room. This corresponds to the measurement of brightness. Let it then have its lens covered by an opal glass. Now, all it can distinguish is the sum total of the light coming in a given direction. This corresponds to an illumination measurement. The scene presented to the camera may contain bright windows or lights, which cause local halation, and dark shadows which will fail to show detail; or, on the other hand, it may be a uniform white sheet. With the lens working, the radically different character of the two scenes would show on the picture. With the opal glass the blackening of the sensitive plate might be the same for each. So illumination measurements may give a totally inadequate description of what the eye must endure.

MEASUREMENT OF BRIGHTNESS.

The actual measurement of brightness is beset with practical difficulties, largely because the brightnesses met with in everyday lighting installations are of a range of magnitude quite beyond the capacity of any one instrument to measure. Thus the ratio of brightness of a tungsten filament to a white surface illuminated by 20 meter-candles is 258,000 to 1, while that between the filament and a shadow on black paper runs all the way up to a hundred million.

Practically, three methods have been used to measure brightness, depending on whether the brightness is high, medium or low. As illustrations of what is meant by high brightness we may take incandescent lamp filaments, in which the brightness or intrinsic brilliancy is of the order of magnitude of hundreds of candle-power per square centimeter. As illustrations of medium brightness take light sources surrounded by diffusing globes, such as opal glass, the intrinsic brilliancy of which may be about 0.25 candle-power per square centimeter. As illustrations of low brightness, take the walls, or objects on the "working plane" of

an ordinary room under a practical lighting installation, having brightnesses of 0.0005 candle-power per square centimeter, or less.

The brightness of a lamp filament may be obtained by measuring the candle-power of a known length of filament whose diameter is also known. The area is then the length times the diameter. A convenient way of making these high brightness measurements is to determine, for one filament of the highest value obtainable, the value in the manner just discussed, at a known total candle-power; determine the variation of candle-power with some controllable variable, such as voltage; and then match the other filaments against this one by superposing them upon its image. By the optical arrangement shown in Fig. 1, it is possible, for instance, to view an incandescent lamp filament upon a Nernst glower image (a^1) background. By varying the current through the glower (a) the filament (b) may be made to practically disappear, which means that the glower and the filament are of equal brightness. In this way values of all the ordinary light sources have been obtained and recorded.[2] Since the number of commercial light sources is limited, it should usually be possible to take their values from tables, thereby avoiding the need for making the rather difficult measurement just described.

The brightness of a diffusing globe is perhaps most easily ascertained by using a definite area as a light source and measuring with a photometer the resultant illumination at some convenient point. Usually the brightness is sufficient, so that the range of a common photometer will permit this to be done. The method of making such a measurement is exhibited in Fig. 2.

The brightness of a ceiling, wall, book page, table top or floor is generally far too low to be handled by either of the above methods, and so in place of the glowing filament of high intrinsic brilliancy used for the first case considered, there is needed some low brightness surface of known value. The only surface with which such things as walls may be directly compared are surfaces which, like walls, owe their brightness to illumination from a comparatively distant light source.

[2] The Measurement of Intrinsic Brilliancies, *Electrical World*, Feb. 16, 1911.

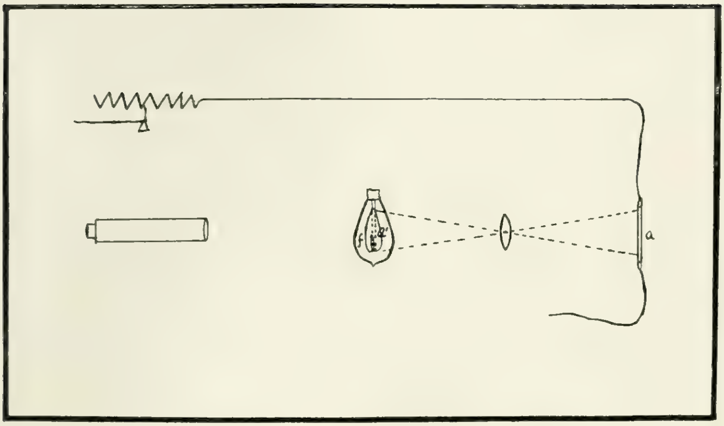


Fig. 1.—Method of measuring high intrinsic brilliancies.

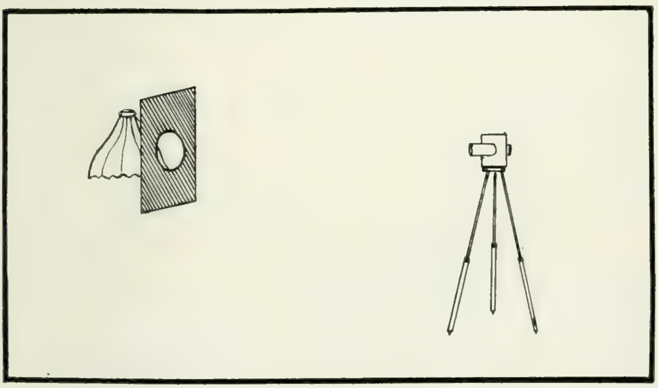


Fig. 2.—Method of measuring brightness of medium magnitude.

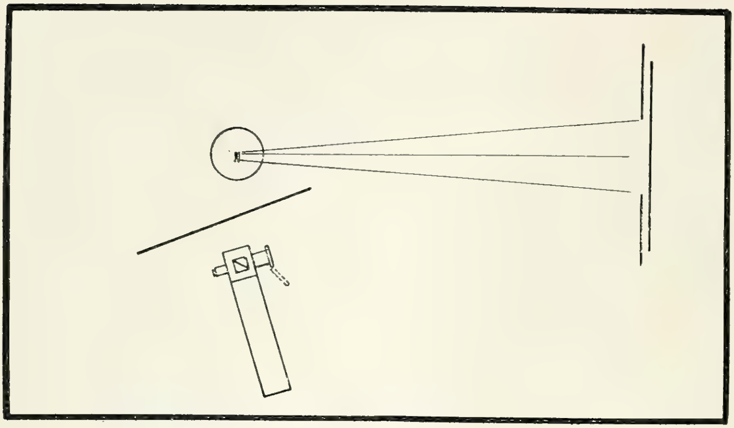


Fig. 3.—The calibration of a photometer for brightness measurements.

Fig. 4.—Brightness values in $\frac{\text{c-p}}{\text{cm}^2}$.

The fact that the illuminated surface in an ordinary photometer field is of this character makes it possible to modify a photometer used for illumination measurements into a brightness measuring instrument.

The field of a photometer consists of two adjacent illuminated surfaces. The illumination of these surfaces is adjusted until they are equally bright, whereupon by using the inverse square law or other expedient and certain constants of transmission and reflection, the illumination at a point, or the candle-power of a source, are calculated. Emphasis is here laid on the fact that really the operation is one of securing equal brightness. The actual value of the brightness of the photometer field is exactly measurable and is not usually recorded, merely because it is a constant which drops out in illumination work.

But suppose that the usual diffusing plate upon which the illumination to be measured is incident be replaced by a darker or a lighter plate. Then the brightness match obtained with the original plate no longer holds. A new setting is necessary, and from this may be calculated the reflecting or transmitting power of the new plate. But suppose, again, that the original plate, when illuminated in a definite manner, had been measured for brightness. Then the scale of the instrument, instead of being divided and marked in terms of meter-candles, could by the use of the proper constant be calibrated in brightness, or candle-power per square centimeter. Now, when the darker or lighter plates are substituted, the brightness can be read from the scale. In place of these extra plates, substitute the walls or the surface in question, as viewed through the photometer when the diffusing plate is removed; then brightness may be obtained by operations exactly similar to ordinary photometry. In order to make this procedure perfectly clear, it is only necessary to carry through by description such a determination. (Fig. 3).

First of all set up a clear white surface of as good a diffusing character as possible. The best surface in some respects is one of magnesium oxid, as obtained by burning magnesium wire under a plane surface (preferably white to start with). White blotting paper is good. Lay on this white surface a screen of black velvet, perforated with an opening of convenient size (such

as 10 cm. diameter). Illuminate the white surface by a high candle-power light source at a known distance. Set up the photometer (supposed in this instance to have a transmitting diffusing glass as its receiving surface) in position to measure the candle-power of the white spot. It will probably be necessary to make use of the absorbing screens or other devices provided for high illumination measurements. A measurement will be made from which the candle-power of the white spot is deducible, and so its candle-power per unit area.

Next remove the diffusing-glass receiving surface of the photometer. The eye placed at the eye-piece then looks straight through at the white surface. *The latter becomes in fact one of the adjacent surfaces of the photometric field.* Adjust the comparison lamp until the field indicates equality. The reading of the scale compared with the known value of the brightness gives at once the constant by which the scale values must be multiplied in order to indicate brightness. It will very probably be necessary to decrease the illumination on the white surface in order to make the new match, but this will cause no trouble if the relative illuminations are known.

Finally there will be obtained a constant which may be used to make a new scale on the instrument—the brightness scale. There will then be two:

(1) The illumination scale (meter-candles) for use with the diffusing screen in place.

(2) The brightness scale (candles per sq. cm.) for use without the diffusing screen.

The procedure just described may be shortened by using constants already known. For instance, a diffusely reflecting surface of reflecting power m has a brightness, when illuminated by E meter-candles of $\frac{m\,E}{\pi}$ candle-power per square meter. (See appendix).

For magnesium oxide m is about 0.95. The labor will be still more reduced when manufacturers of portable photometers will place two scales upon their instruments—illumination and brightness.

The investigator or illuminating engineer furnished with a

brightness scale instrument carries out his measurements quite simply. He places himself at the point chosen as of most interest in the illuminated room and points his instrument here and there like a spy-glass. In fact if the surfaces he wishes to measure are so far away as to be ill defined, he can use a lens to form an image in the focal plane of the eye piece (which is the plane of the photometric field), thus actually making a "brightness measuring telescope." He then selects the brightest spot, the darkest spot, the adjacent surfaces presenting the greatest ratio of brightness, etc. These obtained, the neatest way to record them is upon a photograph taken from the same point. The photograph is itself, if made through proper color screen, a map of brightness, but as usually made possesses no attached scale; nor can any ordinary photographic plate begin to record proportionately the enormous brightness range which exists in most artificially lighted rooms.

Mention should be made here, too, of the fact that in measuring the brightness of walls and furniture the two halves of the photometric field are usually of different color. As a consequence the sensibility is lower than in ordinary illumination measurements and the uncertainty greater. But, for the present at least, the accuracy demanded is not so high. A few per cent. error is not so important where differences of hundreds of times are under consideration.

DISCUSSION OF MEANING AND CHARACTER OF BRIGHTNESS MEASUREMENTS.

The chief place of brightness measurements is in the description and analysis of lighting conditions. It must be remembered that what the eye sees is not illumination, but a distribution of brightness in the field of vision. The eye is a camera which reproduces upon the retina an exact picture of the outside world. Hence to know what the retina is receiving one must analyze exactly what the outside world is from the standpoint of brightness.

Illumination, upon which most stress has been laid heretofore in measurement, must be looked upon merely as a means for producing the brightness distribution. Now, it is in the work of finding what arrangements of brightness in the visual field are

safe or pleasant that the kind of measurements above described are essential. Properly made they constitute a complete map of what the eye sees.

A few illustrations will show more clearly what the distinction between illumination and brightness means. Take first, as the most extreme case, rooms with black and white walls. The walls may in each case receive the same illumination, but it is obvious that the retina does not receive the same stimulation by looking at the white and black surfaces. A measure of brightness on the other hand is a real index.

Take, now, less obvious cases. Consider a room illuminated by overhead exposed light sources. Let the observer, without changing his position, place and remove an eye-shade. While the "working plane" illumination remains constant, his visual field is quite revolutionized from the standpoint of comfort. A plot of the brightness distribution in each case is again a true index of the physical cause of the different effect on the observer. A similar case is presented where overhead lights are raised several feet. The illumination may be lowered, but the visual field is freed from its most glaring features. Consider an observer facing a large-area moderately bright surface, such as a ground glass window. Next let the window be replaced by a black surface in the center of which is a point source of light of the same candle-power as the whole white surface. Now, although the same amount of light enters the eye (*i. e.,* the illumination at the point where the eye is located is identical) the distribution of brightness is radically different, as is the visual effect from the standpoint of comfort.

A practical illustration of this last case is to be seen in buildings where by day a skylight illuminates an area efficiently and pleasantly. At night sharp points of light against a dark background give an equivalent illumination, but which, as far as brightness distribution is concerned, is about as bad as possible.

It is not the purpose of this paper to discuss what constitutes good and what bad brightness distribution, but attention may here be called to a recent admirable analysis of artificial and daylight conditions[3] in which it is shown that the extreme brightness ratio by daylight in a given instance between the brightest

[3] P. W. Cobb, "Brightness and the Eye," *Lighting Journal*, April, 1913.

and darkest visible areas was 400 to 1, while by artificial light they become 100,000,000 to 1. These figures are extremely suggestive; they are brightness and not illumination values.

As remarked above, brightness measurements give the only complete means of describing physically what the retina is receiving from a given lighting installation. They should, therefore, be used lavishly wherever questions of the relative advantage of different schemes of lighting are under discussion.

As an illustration of the subject matter of this paper, Fig. 4, shows a photograph of a living room upon which such measurements have been made. The brightness values are marked upon the photograph, which then, except for color, constitutes a complete description of what an observer sees when occupying the position of the camera.

APPENDIX.

The relation connecting the illumination of a (diffusely reflecting) surface with its brightness is derived by straightforward use of the elementary definitions, as follows:

DEFINITIONS.

I = *Intensity* (candle-power) = luminous flux (emitted) per unit solid angle.

E = *Illumination* = luminous flux (received) per unit of area.

b = *Brightness* = intensity per unit of apparent area = luminous flux (emitted) per unit solid angle per unit apparent area.

m = *Coefficient of diffuse reflection* = ratio of luminous flux reflected diffusely to the total incident flux.

DERIVED RELATIONS.

Now $E\,ds$ = total flux received upon illuminated element ds.

$m\,E\,ds$ = total flux emitted from illuminated element ds.

$b\,ds\cos\theta$ = intensity = luminous flux per unit solid angle from illuminated element, at angle θ from normal.

b may be found in terms of E by calculating the total flux received by a hollow sphere surrounding the element, at distance r, the element being consid-

ered as a light source. We have $\frac{b\,ds\cos\theta}{r^2}$ as the illumination at any point on the sphere, *i. e.*, the luminous flux per unit area on the sphere.

An element of the sphere of area $r\,d\theta\,.\,r\sin\theta\,.\,d\phi$, then receives the flux

$$\frac{b\,ds\,\infty\,\theta}{r^2}\,.\,r\,\mathrm{d}\,\theta\,.\,r\sin\theta\,d\,\phi,$$

whence

$$\text{total flux received} = \int_0^{\frac{\pi}{2}}\int_0^{2\pi} b\,ds\cos\theta\sin\theta\,d\,\theta\,d\,\phi,$$

$$= \pi\,b\,d\,s.$$

This is equal to the flux emitted by the element, whence

$$m\,\mathrm{E}\,d\,s = \pi\,b\,d\,s,$$

$$\text{or}\quad b = \frac{m\,\mathrm{E}}{\pi},$$

b, thus obtained, is in the units employed in designating the illumination. Thus if E is measured in meter-candles, *b* is in candles per square meter. Brightness measurements having first been made upon light sources, which are of high brightness, it happened that the centimeter was chosen as the unit of area for brightness in order to avoid excessively large figures. Measurements of wall and similar surface brightnesses could more conveniently be expressed in candle-power per square meter.

DISCUSSION

Dr. C. E. Ferree (Communicated): I have very little to say in the discussion of this paper other than to express agreement with Dr. Ives as to the importance of brightness measurements in the specification of the illumination of a room. My own original analysis of the factors in lighting that are of importance to the eye, although not expressed in Dr. Ives's terminology, gave to the distribution of luminosity or brightness in the field of vision first place, and my selection of the first set of lighting conditions to be tested was based primarily on this factor. That is, the fixtures selected, the position of the observer in the

room, and to some extent the room itself, were all such as to provide for the four test conditions wide variations in the range of brightness of the objects that fell within the field of view. Moreover, the prime importance of presenting to the eye a field of view properly graded in luminosity has been strongly emphasized in each of the three papers I have presented to this Society on the ability of the eye to maintain its efficiency for a period of work.[1]

In recognizing the importance of brightness measurements in the specification of the lighting of a room, however, it must not be overlooked that the distribution of brightness depends upon at least two sets of factors: (a) the coefficients and types of reflection of the different surfaces in the room; and (b) the amounts of light travelling in the different directions. That is, the brightness distribution is in part characteristic of the room itself and in part dependent upon the type of fixture and installation. In a careful specification of the lighting of a room both of these factors should be taken into account. This can best be done by making both brightness and illumination measurements.[2]

It can scarcely be accomplished by brightness measurements alone.

[1] For example, the three reasons given in my first paper why direct lighting fixtures of the type I used caused greater loss of efficiency than daylight illumination, were all expressed in terms of the muscular strain required for the eye to adjust itself for its work when the field of vision contains surfaces of much greater brilliancy than the work, all in different directions and at different distances from the eye. It was also stated in this paper that if the fixation and accommodation of the eye for a given object is to be accomplished with a maximum of comfort and a minimum of strain, the illumination of the retina should fall off more or less uniformly from fovea to periphery as it does when there are no great extremes of luminosity in the field of vision. In two of the papers it was claimed that the fundamental cause of damage to the eye in our present lighting practise is the presence of bright sources of light in the field of vision; and that until these are eliminated or greatly reduced in intensity in home, office, and public lighting, we can not hope to get rid of eyestrain with its complex train of mental and physical disturbances. In other ways in these papers both in the section on the effect of varying distribution and of varying intensity, the importance of a better gradation of luminosity in the field of vision was strongly urged, especial stress being laid on the ratio of brilliancy of objects in the surrounding field to the surface brightness at the point of work.

[2] Such a specification has now been made of the lighting of our test room. Brightness measurements have been made of all surfaces which on inspection showed a considerable variation from the mean, and illumination measurements have been made in different directions from the working plane at 66 stations. These measurements had been started but could not be completed before the presentation of the paper at the Pittsburgh meeting giving the results of the tests. More especially will it be of importance to include in the specification both kinds of measurement if ultimately it is found more feasible to make our classification of lighting in terms of type of fixture rather than in terms of illumination effects.

Under the heading "the most striking characteristic of brightness," Dr. Ives makes the statement, "A bright surface is equally bright whether one views it from 1, 10 or 50 meters." Two points may be raised with regard to this statement. (1) Even so far as the brightness of the image on the retina is concerned, this statement could be assumed to hold only when a constant breadth of pupillary aperture is maintained. One of the pupillary reflexes is a change in size with change of distance of the object viewed. As the pupil changes in size, different amounts of light are concentrated into the image on the retina which operates to destroy the balance that obtains between the light flux entering the eye and the change in the size of the solid angle subtended by the bright surface, when the imaging is done through an aperture of constant breadth. (2) The statement seems to be made in terms of sensation as well as in terms of physical image on the retina. This interpretation the writer gets both from the wording of the sentence quoted and from the discussion that follows it. Since the same impression may be given to others, the following brief additions to the discussion contained in the paper may not be out of place. In its natural functioning, *i. e.*, unmodified in its action by any particular type of apparatus, the eye does not see its objects of the same brightness regardless of their distance. It cannot be assumed, for example, that a surface of a given light density will be seen of the same brightness at 1, 10 and 50 meters. Such an assumption is in general not only contrary to experience but it can not be verified by test.[3]

In confirmation of this statement, the results of two types of test recently made by the writer will be cited. In the first, the stimulus or surface viewed was of matt milk glass 45 mm.^{2} illuminated from behind to a brightness of 0.0010 candle per square meter. The brightness of this surface was cut down by means of a sectored disk until it could just be seen at distances of 1, 4, and 7 meters. To just be seen at 1 m. the total value of open sector required was 14.4°; at 4 m., 45°; at 7 m., 135°; and at

[3] Without resorting to further experimentation, at least three good reasons may be given why such an assumption can not be made. The analogy of the eye and the camera should not be carried too far. It ends with the focussing of the light on the sensitive screen.

10 m., 215°. Thus the surface density of light needed to just be detected was 3.13 times as great at 4 m. as at 1 m.; 3 times as great at 7 m. as at 4 m.; 2.33 times as great at 10 m. as at 7 m.; and 21.2 times as great at 10 m. as at 1 m. The series was not carried out to 50 m. The tests were made in a dark room, and in order to keep the sensitivity of the eye as nearly constant as possible, 30 minutes of adaptation were allowed before the series was begun. For the point in question this type of test is the most sensitive known to physiological optics, *i. e.,* it is a threshold test made with the dark-adapted eye. The difference in the effect produced by change of distance as determined by an equality or a just noticeable difference test with a light-adapted eye and with higher intensities of stimulus would not, for example, be so great. In making these tests, 6 observers were used in all. The above results are typical. The second test might be called photometric in principle. It was so simplified, however, as to leave the eye as free as possible to function for the distance factor in seeing its object. A comparison field was made to match a given surface in brightness illuminated to a brightness of 0.0010 candle per square meter at 1, 4 and 7 meters. At 1 m. distance the match was gotten with the lamp illuminating the comparison field at 1.17 m. from the photometric screen; at 4 m., with the lamp at 1.47 m.; and at 7 m., with the lamp at 2.16 m. This test was also made in the dark room and repeated a number of times.

It will be understood that we are discussing here the natural functioning of the eye to the distance factor, not its functioning as modified by any particular type of instrument. With the eye functioning naturally the apparent brightness of an object is not independent of its distance from the observer, and if in making the photometric determination an instrument is used which so modifies the functioning of the eye as to eliminate distance as a factor in seeing, *i. e.,* keeps the pupillary breadth, the visual angle, the projection distance of the image seen, etc., constant, this effect should be distinguished in a general statement of principle from the natural functioning of the eye.

Mr. M. Luckiesh (Communicated): Those engaged in investigating the problems relating to illumination and vision have

long realized the importance of the distribution of brightness in the field of view. Some years ago the relative merits of light and dark walls were much discussed but no general agreement was reached. Dr. Cobb finds no great difference in one's ability to distinguish fine detail or brightness differences of adjacent areas whether the surrounding field be of the same brightness as the mean brightness of the test object or relatively dark. These observations did not include the measurement of fatigue. Experience and the general attitude of experts toward this question indicates that very considerable latitude is permissible, provided excessive contrasts are avoided. For some years the writer has included brightness measurements in his investigations of lighting conditions and several years ago roughly imitated daylight brightness distribution in an interior by means of dummy windows illuminated by artificial light.

Dr. Ives states that the task of the lighting engineer is to produce in the field of view a distribution of brightness possessing certain desirable characteristics. This is true from the standpoint of eliminating excessive contrasts and high brightness from the field of view. The field of the lighting expert, however, will perhaps always be found largely in the illumination of the decorator's work. It is the business of the lighting specialist to keep contrasts and intrinsic brightnesses within certain limits (the permissible maxima being unknown at present); any dogmatic effort on his part beyond that is somewhat presumptious. The decorator is to be considered, for after all when the lighting experts have kept within safe limits, the distribution of brightness and color is his business. Here one will find that tastes differ. For instance, many people are not in accord with the scheme of imitating natural lighting in interiors as tried out by the writer some time ago* and more recently considered by Ives. Also the great differences in brightness distribution resulting from present practise with various systems of lighting indicates a wide difference in taste which is very likely only a harmless difference of opinion when the systems are well designed.

An interior can be likened to a picture with its foreground, middle distance, and sky. The distributions of color and bright-

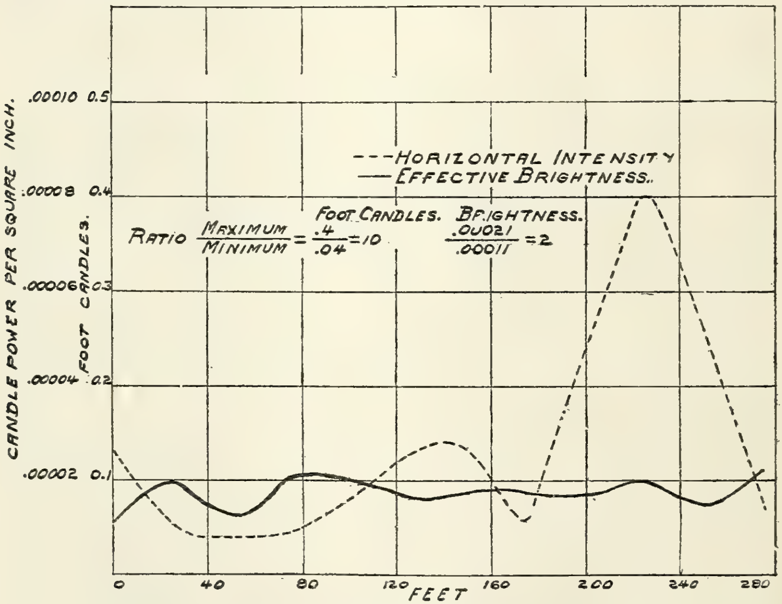
* TRANS. I. E. S., pp. 398, 405, 1912.

ness found in pictures are indeed varied and will ever be so in rooms in order to please the many varied tastes. The importance of the esthetic side of lighting is growing and must be considered quite an important aspect. Therefore, a map of brightness is almost superfluous information when dangerous contrasts are absent and the lighting system is well designed, unless this map is for the decorator's edification. Illumination measurements will continue to meet with much favor, for such data informs the lighting engineer as to the possibility of reading, sewing, or the performance of the many other operations for which light is also used. Of course if the occupant of the room expects to place his eye at the position of the camera which was used in making the ground for the brightness map and remain content to gaze at the picture which the room presents, then brightness measurements are of highest importance. However, much of the time eyes are otherwise engaged. When the eye is engaged in other work besides "sight-seeing" the brightnesses of the surroundings become more or less blurred upon the retina and the map of brightness as now seen is somewhat remodelled. The writer in experimenting with the matter of brightness in the field of view finds no discomfort arising from dark walls when the eyes are permitted to wander as in ordinary conversation. However, repeated tests in reading from white paper viewed against dark walls in the background with the light falling from a source high in the rear of the reader noticeable discomfort and eye fatigue invariably resulted. This fact has convinced the writer that even moderate contrasts under some conditions are to be avoided. Experiments performed outdoors under a bright sky showed that the eyes suffered no discomfort under the conditions surrounding the experiments when they were subjected to no exacting work, but serious discomfort was felt as soon as the eyes were subjected to reading fine detail. This indicates another fact which must be considered, that is, the nature of the work required of the eyes.

Brightness measurements are valuable in research investigations and certain measurements of maximum contrast and maximum brightness should be recorded in many studies of illumination conditions; but the measurement of illumination will continue

to be of highest importance from the standpoint of furnishing useful data regarding the adequacy of the illumination for performing the many operations involving vision. Of course pure illumination measurements have long been recognized as inadequate in determining the effectiveness of illumination for the many varied operations for which eyes are used, but these measurements are more useful than any other one kind of observations for the general requirements of the lighting specialist.

MR. PRESTON S. MILLAR (Communicated): Dr. Ives' paper calling attention to the importance of brightness measurements in the study of illumination is of timely interest, since practitioners are beginning to appreciate the importance of such measurements and to inquire concerning their nature.



Horizontal illumination from arc lamps and corresponding curve of effective brightness. Street paved with asphalt.

Some indication of the growth of appreciation of the importance of brightness (or intrinsic brilliancy) measurements will be found upon a review of the TRANSACTIONS of the I. E. S. Prior to 1910 little or no attention was given the subject. In 1910 it received some attention, and since that time appreciation of its

importance has grown until now it is generally recognized that both illumination intensity and brightness data are essential to intelligent study of the subject.

Dr. Ives has discussed the importance of brightness measurements in indicating contrasts presented to the eye by adjacent surfaces of widely different light projecting qualities. I have been interested as well in studying through brightness measurements the effectiveness of the illumination of street surfaces where the variables encountered are due to differences in the angle of incident light rather than to differences in the light reflecting qualities of different portions of the surfaces viewed. Such data are shown in the accompanying diagram.* To the claims emphasized by Dr. Ives for the importance of measurements of brightness this may be added.

Mr. F. K. Richtmyer (Communicated): I am particularly interested in Dr. Ives' paper, partly for pedagogical reasons. It is clear and concise, and contains a happy compromise between the abstract and the concrete. After reading it one has a feeling that he has really learned something of decided practical importance.

I am further interested because the paper is representative of the changing attitude of the illumination specialist. At first, he studied candle-power. Later, say eight or ten years ago, he began to study illumination. Now, he is beginning to pay special attention to physiological effects and, as Dr. Ives points out, to realize that illumination intensity measurements are entirely inadequate to determine the effect of any given illumination system on the retina. This gradual evolution is somewhat astonishing to those who are interested in the educational side of illuminating engineering.

The field of the electrical engineer is perfectly well defined. Mathematics and the physical sciences, both pure and applied, cover the ground upon which instruction must be given. The illuminating engineer, however, must be well grounded not only in all these; he must receive instruction of a highly specialized nature in ophthamology, psychology and architecture. In short,

* "Some Neglected Considerations Pertaining to Street Illumination," Trans. I. E. S., pp. 661-667, 1910.

he must be familiar with all the phenomena of light production from the coal pile to the human brain.

This paper deals particularly with the physics of surface brightness. The next logical step would be for some member to present a similar survey of the question of the physiology and psychology of surface brightness.

Dr. C. H. Sharp (Communicated): It is well that Dr. Ives has presented this very clear exposition of the importance of measurements of brightness and of the method of making them. There has been much discussion of brightness in the papers presented to this Society but relatively little has been said about its measurement. This has not been due to the lack of apparatus for making such measurements, for most illumination photometers can be used for this purpose, and in some cases at least, a constant is given in the instrument certificate by means of which the indications of the scale in foot-candles can be converted into readings of the brightness of any surface at which the photometer is aimed. Hence data on brightness become almost as easy to get as data on illumination.

It should be emphasized that brightness data and illumination data cannot be made to replace each other; they can only supplement each other. The illumination data show only the light flux received, and give only by implication or interpretation an idea of how bright the surfaces receiving it appear. Brightness data on the other hand, show how actual, natural objects look in a given case and do not show how much illumination has been required to produce the observed effect. Therefore if we want to know how the flux generated is utilized and distributed, illumination measurements must be made; if we wish to analyze the effect produced in a given installation, or to study conditions from a physiological standpoint, brightness measurements are all important. For complete descriptions of illumination effects data on both illumination and brightness are required and the measurements of brightness to supplement those of illumination can be made with the same apparatus and with little additional trouble.

Mr. G. H. Stickney (Communicated): Up to the present, nearly all of the investigations of light and illumination have been based upon the flux of light from light sources up to the

point at which they fall upon certain surfaces to be illuminated. We have made a considerable study of the magnitude of illumination falling upon such surfaces, but, owing to the complexity of the problem, have frequently ignored the light reflected by those surfaces to the eyes of the observers. That such surfaces do introduce very important factors in connection with our ability to see them has always been admitted and it now begins to appear that we have sufficiently mastered the problem up to this point to warrant carrying the investigation on in such a manner that we may analyze the effects received by our eyes.

The method proposed, as described by Dr. Ives, is the logical one for completing the chain and it is probable that in the course of a few years we will be able to interpret the effects in terms of the actual and relative intensities received by our eyes from the various illuminated surfaces. When this is established, unquestionably illuminating engineering study will give a great deal more attention than at present to the color and nature of the surface to be illuminated, whereas to-day our thought is very largely concentrated on the light proceeding from the original sources themselves. It is not likely that a complete analysis by the brightness method will be made in connection with the planning of a majority of individual installations, but rather that such methods will be employed in establishing laws of illumination and simplified rules for their interpretation. In this connection, the method of investigation outlined by Dr. Ives is likely to assume very considerable importance in the future advances of lighting practise, decoration and design, especially for those conditions in which artistic effects and comfort of vision are of importance.

Dr. H. E. Ives (In reply): In regard to Prof. Ferree's discussion, I must express first of all my most cordial disagreement with his comment on the proposition that two equally bright objects unequally distant look equally bright. This he says is "an assumption not only contrary to experience, but it cannot be verified by test." On the contrary, it is a necessary consequence of the laws of geometrical optics and has been verified by test many times.

The experiments quoted by Prof. Ferree do not to my mind

affect the essential correctness of the subject matter of the paper, none of which, by the way, claims to be new or inviting to discussion. His tests on threshold vision have no bearing on the question. For it has been known that at the threshold where ideas of distance and form are lost the eye is scarcely an optical instrument at all. The perception of light then depends not alone on the brightness, but on the extent of the test surface. Prof. Ferree's test object was no larger in area than a dollar and was viewed at distance as great as ten meters; therefore, under conditions particularly suitable for exhibiting the peculiarities of threshold vision. In ordinary illumination work these phenomena of excessively low illumination play no significant part.

In describing his second experiment he merely says it "might be called photometrical." If by "photometrical" Prof. Ferree means that the test and comparison surfaces are viewed in juxtaposition, then some other explanation than his suggested pupillary changes must be found for the results he reports. For it should be obvious that if the pupil changes diameter as one's attention shifts from the near to the distant object, this affects the brightness of the image of each object alike. In other words the pupil cannot at the same time be one size for the one object and another size for the other object with which it is being compared.

The true explanation of what he reports is possibly to be found again from consideration of the illumination employed. This, from the figures given, is only a few times the threshold value. A brightness of 0.001 candle-power per square meter is less than that of black velvet under the very low illumination of one meter-candle. Until Prof. Ferree gives us a more definite description of his experiments the most one can do is to conclude he has obtained results dominated by twilight vision phenomena and has drawn conclusions as to normal illumination conditions. There occurs to me several ways by which results of the kind reported by him could be obtained, none of them due to any deviation from the equal brightness law.

THE RELATION OF THE ILLUMINATING ENGINEER TO THE PROBLEMS OF FIXTURE DESIGN.*

BY A. B. WILSON AND F. J. BLASCHKE.

Synopsis: The qualifications and functions of the illuminating engineer are discussed in the following paper. Some of the problems and conditions which confront him in planning lighting installations are also mentioned. Brief reference is made to interesting improvements which have been effected in recent years in the design and manufacture of fixtures and lighting accessories.

The illuminating engineer in his office as the judge in the question as to what directing and supporting devices shall be employed, has it in his power to enhance the artistic value of a lighting installation or to mar it to such an extent that no economic advantage that may be proved can compensate for the offense it offers to the normal sense of harmony.

The illuminating engineer prescribes to a great extent the direction in which the activities of the fixture designer shall lead. Viewing the proposition from another angle, it could be said that the illuminating engineer works with the products of the fixture and reflector designer, but when it is considered that the verdict of the engineer is, in the majority of instances, the basis upon which lighting apparatus must make its appeal the engineer appears as the real governing factor.

From the illuminating engineer's experience it is learned that ancient and obsolete forms of illumination, which are often attractive because of their quaintness and their appeal to sentiment, can be reproduced with modern illuminants without the burden of excessive operating cost. When such facts are made known generally there is at once demand for the things they involve and then the lamp, fixture and reflector designers bend their energies toward the production of candelebra units, electrical torches, luminous fireplaces and such other devices that serve to satisfy the sentiment that demands them.

* A paper to be read at a meeting of the Pittsburgh Section of the Illuminating Engineering Society, January 16, 1913. Subject to revision for the TRANSACTIONS.

In the commonly accepted sense the lighting fixture is an apparatus which serves to support a light source and whatever appurtenances are employed to direct or control the light. Perhaps including all the parts of a lighting unit, excepting the light source, under the term fixture would be more consistent with the nature and purpose of the apparatus and also permit a broader treatment of this subject; but custom and usage have made distinctions that cannot be so easily ignored. In cases where one has to deal with only a light source and its support, the situation is sufficiently clear, but where there is another object such as a reflector or some other controlling medium to be considered due notice must be taken of the fact. There are, therefore, under present usage three essential elements which must be recognized when considering a lighting installation—the light source, the fixture and the controlling or distributing medium.

The primary object of a lighting installation is to provide light enough for one to see with ease and comfort or at least without an undue strain upon the optic centers. To the uninitiated it would seem that to provide such an installation would be a simple matter indeed, but upon closer study the question reveals the difficulties involved in the determination of quantity, quality, direction, intensity, control and numerous other important factors, and it assumes an entirely different aspect.

The engineer must have the talent to combine in their correct proportions the elements of efficiency and decorative value when applying illumination. Although these elements are not of equal importance, in many instances both must be duly regarded if the most satisfactory results are to be obtained. Too often have the fixture, reflector and lamp manufacturers suffered because of the incorrect balancing of these elements or the entire disregard of their relationship. Through a long period of training and consequently a thorough appreciation of the efficiency factor as primarily important, the engineer may err in judging the merits of a unit. The efficiency of a unit can be expressed in cold figures; decorative value and appearance are matters of taste and appropriateness and the designer must take into consideration the idiosyncrasies of the probable purchaser of the product after it has been interpreted in metal and glass. The engineer should be able and willing in measuring the merits of a unit to

Fig. 1.—An example of early fixture design.

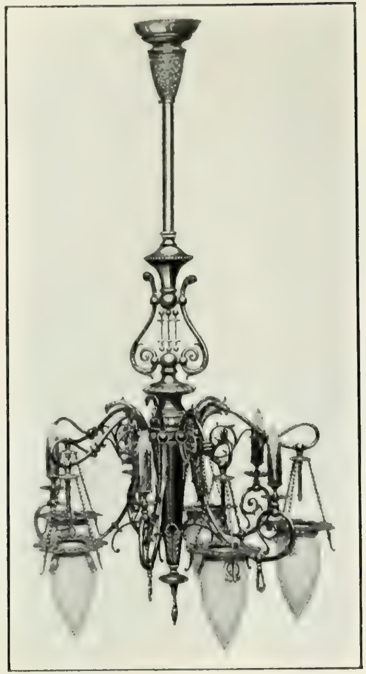


Fig. 2.—An example of early fixture design.

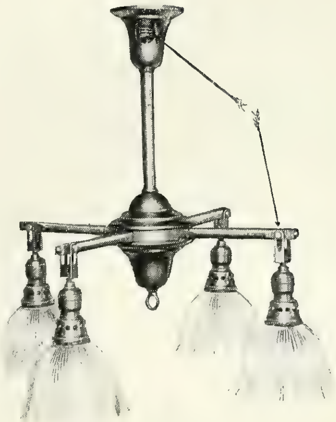


Fig. 3.—Adapting the fixture to the illuminant. Protection for the early tungsten lamp by spring and swinging suspension.

Fig. 4.—The link between the old style fixture and the beginning of the modern type.

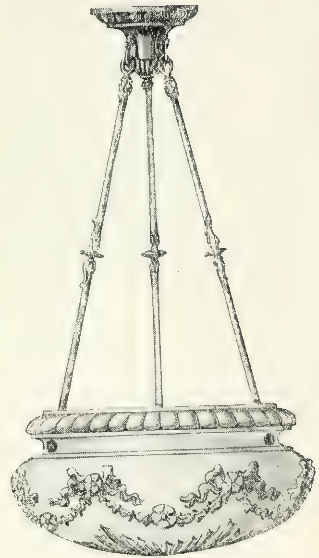


Fig. 5.—Artistic merit expressed in a modern simple design.

see beyond the plain data obtained by means of a photometer and a wattmeter. If every illuminating engineer would attempt in every instance to provide a given intensity of illumination with the smallest number of units and at the lowest cost, there would be very little demand for the talent of a true artist in the designing room. Fortunately, we are not so devoid of appreciation of the beautiful or so mercenary as to measure merit in dollars and cents alone. One does not value a Rembrandt by its area or purchase on the basis of the amount of paint used. It is possible to present to the public lighting units that have value as artistic interpretations which wins for them the encouragement of acceptance by the ultimate consumer. The reports of new designs in fixtures and glassware that come to notice almost daily are the best evidence that there is a demand for something other than units whose sole appeal pertains to the pocket-book.

The economical production of light encourages its free use, just as the low cost of any commodity will tend toward an increase in the demand for it. Economical merchandising merits the interest of the crowd and in the sale of artificial light it is well within the truth to state that the price tendency is downward. To-day the householder, the merchant, the city council, the board of trustees and whoever else authorizes and oversees the expenditure of funds realizes the relatively low cost of operation of modern lighting units—which tends toward the employment of greater numbers of units and more elaborate designs. All this means that the fixture designer must be active to meet the demands upon his talent. The fixture industry must acknowledge the stimulating effect of the great reduction in the cost of lamps, especially those of the incandescent electric class, that has been accomplished within the past three years, for the business of the manufacturers has taken on its present day activity not so much because of their own efforts as on account of the attention directed toward them through the public realization of the economy and convenience of artificial light.

Since scientific lighting began to command the attention it now receives, the usual order of procedure has been to suit to the light source the other factors in a complete lighting installation. Reflectors, diffusers and fixtures have been designed mainly with

a view toward accommodating a given size or capacity of light source, and in many cases, with a possible exception of the purely decorative installation, the customary procedure is logical. The light source being the most essential factor in the problem of illumination it received the first attention and consequently was first brought to a reasonable degree of perfection. With the realization of the possibilities for giving a lighting unit additional value as an ornament, the problem of fixture design was taken up. With improved light sources, notably the tungsten lamp, a scientifically constructed lighting unit was instrumental in bringing about early commercial success; and to utilize this illuminant economically the question of reflector design was attacked with renewed interest. In fact so important has this phase of light production become that competition is more keen among the champions of various distributing media than among the producers of lamps.

The task of selecting from among the three essentials, lamps, fixtures and reflectors, units that are not only suited mechanically but also answer the requirements from an artistic standpoint, falls largely to the illuminating engineer. When the fixture maker has interpreted his ideas in metal and the reflector designer wrought to the best of his ability in glass or other materials, it devolves upon the illuminating engineer to select from the work of these two, pieces that will harmonize and at the same time permit the lamp maker's product to perform creditably. The use of fixtures entirely out of harmony with other surroundings, even by the most inexperienced amateur, should be considered inexcusable; but unfortunately the combination of glassware with supporting devices never intended to be employed in conjunction therewith is frequently condoned. It is to be regretted that so many examples of the incorrect application of the elements of a lighting unit exist. The purpose and the idea which the originator has in mind is too often defeated in the application of the object. Obviously the engineer who makes the recommendation is at fault, but perhaps in the future designers will foresee such contingencies and prevent the misapplication of their products by specifying what combinations are permissible.

It is a matter of record that the selection of by far the greater

part of the class of fixtures suitable for decorative purposes is made by women. To the hard headed commercial man an argument from the standpoint of efficiency may have the greater weight, but it will hardly be disputed that attractiveness in design and the quality of harmonizing with the other decorations in a home makes the stronger appeal to the feminine mind. Experienced designers and those whose business it is to reflect the charm and appeal of furnishings and decorations in lighting fixtures assert that it is well to remember the part played by women in fixture selection and add that the illuminating engineer should be cognizant of the same facts.

When fixtures are designed for the homes occupied by people of moderate means the style must necessarily lean toward the conventional and, although still a second consideration, the efficiency of the complete lighting unit must be given attention. In the case of industrial illumination, principally in the lighting of shops and factories, efficiency is of major importance. Where the designer is called upon to plan fixtures to complete a scheme of decoration he should sacrifice nothing for efficiency. The cost of operation in such instances is not of such vital importance as it is to the householder of limited means, and therefore the fixture designer should not be compelled to work under the handicap offered by an anticipated test of watts per square foot. Unorthodox as it may seem, it is true that in some instances the illuminating engineer takes no part in the fixture designer's work other than to determine the amount of light required on a given plane.

Because the art of lighting did not change for a considerable number of years, consultation with the lighting engineer when plans for a structure were laid was postponed until all other details had received attention. Though there has been a great awakening to the possibilities in illumination, the old order has not materially changed, with the consequence that the fixture designer and the engineer are often handicapped by conditions which might have been improved if these authorities had been consulted before decisions pertaining to them were made. Often the designer when called upon to carry out a period interpretation is compelled to work under the difficulties of color limitations

and unfavorable architectural arrangement. Although it is a mark of merit in design and engineering to be able to conform to existing conditions with pleasing results, it is being realized that allowing the exponents of light and its application a voice in creating the conditions, results more satisfactorily.

The importance of the illuminating engineer is continually being realized to a greater extent. In planning illumination of subjects such as tennis courts, golf courses, works of art and in the specific lighting necessary in some industrial plants or, in general, wherever extraordinary control of light is required, there is an opportunity for co-operation between the fixture designer and the illuminating engineer. The illuminating engineer in studying the problem at hand can determine to a nicety the requirements in the amount of light and its direction and intensity, but to devise apparatus which will enable him to support the source of light properly to accomplish the object intended requires the help of the fixture maker and the reflector man. Manufacturing problems must be taken into consideration in the design of a lighting fixture, for it often occurs that demands made by the illuminating engineer cannot be fulfilled because of mechanical obstacles encountered by the manufacturer that make it entirely impracticable to carry out a particular idea. The designer and the manufacturer being in close touch with the limitations of fixture making, the engineer can profit by consulting with them when unusual problems are presented. To embody in a recommendation the best in art, science and mechanics is to approach perfection in the sense of a service rendered.

An instance of an opportunity for co-operation between the illuminating engineer and the fixture designer is the awakening of interest in an artificial substitute for daylight. A number of attempts have been made to approximate daylight by the modification of artificial light, but it is only very recently that any promising device for accomplishing this result has been produced. Very naturally the use of artificial daylight is at first restricted to a very limited area by means of screening apparatus, but when the great advantage of the availability of true daylight at all times is realized, it will be the problem of the illuminating engineer to specify intensity, the location of outlets and how to

arrange for the correct illumination of adjoining areas having artificial light and correct daylight. Upon the fixture designer comes the task of producing supporting apparatus suitable for applying the principles followed in producing artificial daylight and the necessary co-operation with the illuminating engineer in carrying out the plans at hand.

The development of new illuminants continually offers problems for the engineer and the fixture designer. When it is once determined how an illuminant should be used and what purpose it can best serve, the fixture designer must apply his talent toward

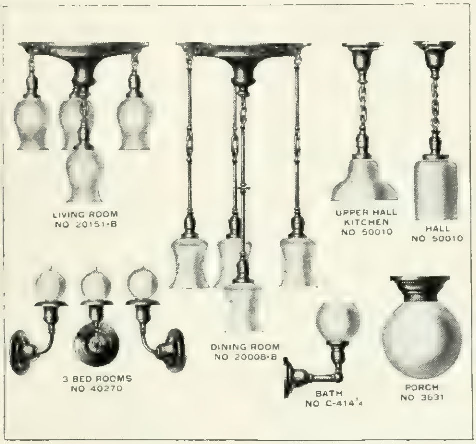


Fig. 6.—An example of the modern idea in conventional fixtures for the home.

providing apparatus suitable for adapting it most profitably. The recent developments in tungsten lamps offer a good example of the proposition just mentioned.

Among the baleful influences preying upon the fixture industry and one that retards progress and development, perhaps more than any other thing, is the activity of the unscrupulous manufacturer who sees no farther than the disposal of his goods, his sole object and aim being present and immediate profits without a thought for the future or the effect that such indiscriminate merchandising has on his contemporaries. One untrustworthy pirate can create sufficient dissatisfaction in the public mind to

undo the work of a dozen advocates of honest practise. It is a fact recognized by both the engineer and the commercial man that the design, manufacture and adaptation of lighting fixtures requires a knowledge of the arts and the exercise of more than ordinary discrimination. With the sole object of disposing of as much goods as possible at a profit as great as his unsuspecting victims can be made to surrender, the "profit first" fixture pirate can not maintain the correct attitude toward the industry in which he engages. Illuminating engineers would do well to be informed regarding the producers and distributers of goods used in the application of their plans that they may aid in discouraging the

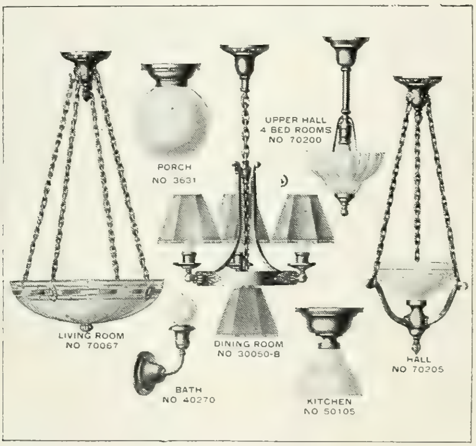


Fig. 7.—A suggestion of a period interpretation though suitable for any delicately furnished interior.

undesirables. The good offices of the National Registration League in this direction are worthy of universal support.

Among the results due to the reduction in the cost of light, that is, particularly in the cost of providing the light source itself, is the extensive development of apparatus for applying light indirectly. Only in rare instances where natural conditions are favorable can indirect lighting be accomplished without the use of directing and diffusing media. Before the present high efficiency light sources were developed, the necessity for directing and diffusing media was not realized to the extent it is to-day.

Because of the relatively low light value of the individual units it was difficult to convince the commercial world of the economy or advantage of directing apparatus. The argument that such apparatus would serve as a protection to the optic centers as well as increase the efficiency of the lighting unit could not be consistently proved. The high intrinsic brilliancy of modern units, however, made evident the necessity for protection from direct rays and opened the way for the development of apparatus that would make it possible to utilize under proper hygienic conditions the greater part of the light produced. As a device that fulfills both demands, the semi-indirect unit has been extensively advanced.

If we go back to our school days we can perhaps recall that our teachers instructed us to protect our eyes by sitting at our desks in the proper position to avoid direct light, even though it was only that which was transmitted through the windows. People have learned in ages past that the eyes are injured when subjected, even momentarily, to a strong light, and by their use for a considerable period in a more moderate light. Although this was realized when artificial light was accomplished in the primitive way and injury to the optic centers was more likely to be the result of too little rather than too much light, the necessity for protection against eye strain was very forcibly brought to attention when modern high efficiency light sources were developed. In earlier days the necessity for the use of artificial light was not so great as the activities of the modern age demand, hence, protection against too intense light did not receive the serious consideration it is given at present. The conservation of vision has been made the subject of special study and investigation only since the extreme necessity for it has been evident. Physicians and others whose activities brought these problems to their special notice have long realized that the eyes do not receive the consideration and care that they require. Like other great truths that pertain to humanity in general, it is only when the layman is impressed through personal experience and demonstration that sufficient interest is aroused to secure action toward a change in conditions. The modern public will accept indirect lighting not because of the data that proves its efficiency but

because it realizes through experience that something which provides the advantages of indirect lighting is necessary for the protection of the eyes. Likewise, the Anti-Glare Society finds a fertile field of endeavor because the public has been brought to recognize through personal and even painful experience a truth of which it has long been dimly conscious. But what has this to do with fixture design? We may answer, everything, for the correct application of the principles which counteract the injurious effects of too much light and the correct manner of bringing it to the eye cannot be accomplished without the use of apparatus that sustains the light source and controls the light, the planning of which requires the attention of the designer and the engineer.

Previous to the advent of high efficiency units, light directing apparatus was confined chiefly to the class of apparatus designed for applying light directly. Consequently, the problems of the fixture designer did not involve the production of fixtures for accommodating diffusing units in which the indirect components are of principal concern. The problems, then, of providing supports for indirect units is comparatively new and therefore very worthy of careful attention. Because the designer of fixtures for indirect and semi-indirect units must take into consideration the obstruction that his product may offer to the light that it is desired to apply to the working plane, the task is more difficult than the planning of fixtures in which artistic merit and mechanical strength are practically the only requirements. The ideal support for an indirect or semi-indirect lighting unit is one that offers no obstruction whatever in the direction from which the greater part of the light is intended to be utilized. However, it is evident that such an advantage is possible only in cases where the area to be illuminated is designed with this fact considered. There are a number of striking examples of ideally designed indirect and semi-indirect lighting systems which are constructed on the plan mentioned. In nearly every instance the installation of such lighting systems was anticipated in planning the architectural features of the structure involved and therefore the usual difficulties offered by the necessity for suspending units from a ceiling were not encountered. Since a great percentage

of lighting systems are planned to replace obsolete types or unsatisfactory units, the engineer and the designer must adapt their products to existing conditions. The desire to avoid obstructions to the light has caused designers of indirect and semi-indirect units to limit the supports to single stems or numerous slender rods or chains, with an effort to add artistic value by means of additional parts arranged below the light source.

Here the engineer and the designer of fixtures and glassware find a subject for thought. To secure the best interpretation of the basic idea of the design, the addition of parts for purely decorative purposes requires a study of proportion, a regulation of the brilliancy of the lower surface of the unit and the harmonizing of the fixture and glassware.

When the entire field is surveyed and the contingencies which bring the illuminating engineer into contact with the problems of fixture design are reviewed, the relation of the one to the other is seen to be governed by the laws of co-operation. With the union of effort regulated by the nature of each individual problem, it will readily be appreciated that there are instances when the services of the engineer are not required, though such situations arise infrequently. Nevertheless, it is highly important that these cases be given due consideration because they are of great moment to the designer. For the good of both and for the best interests of the lighting profession there must be harmony between these two important factors, a condition which is growing with the awakening to the real meaning of illumination.

DISCUSSION.

MR. E. B. ROWE: There is too frequently a wide difference between the fixture designer's conception and its actual application. The designer may spend a great deal of time and thought on the details of his fixture, but the sale of the fixture usually depends on the caprice of the fixture salesman or the personal preferences of the buyer. I am speaking now of the usual run of fixtures which are sold for the average home, but undoubtedly the same conditions prevail in the selection of lighting fixtures for costly residences. I will cite just one instance to illustrate my point. Over the front entrance of a pretentious residence on Euclid Avenue, Cleveland, is suspended a lantern type fixture

on a suitable bracket, so that its daylight appearance is very pleasing. The glass sides of the lantern are vertical, however, and since the bottom of the fixture is entirely opaque, you can readily imagine how little illumination is secured directly below and for a distance of some fifteen or twenty feet out in front of the door. So although this fixture is a thing of beauty by day, it is absolutely atrocious by night, because it lights only the top of the door and the Colonial panel above it, leaving the bottom of the door and the flight of stone steps and the walk leading up to it in almost complete darkness. Such a lack of the necessary illumination is an invitation to a misstep and perhaps a serious accident.

In the course of their paper, the authors speak of indirect lighting as being a new development; but they say there is nothing new under the sun and this is undoubtedly true of indirect lighting. In that connection, I recall an illustration of a very old lighting installation which made quite an impression on me. In the course of a series of illustrated lectures on the Early Christian Church and the origin of the Bible, one crude drawing showed a hanging fixture consisting of an opaque bowl, suspended on chains from the ceiling of the temple and containing, presumably, one of those early oil lamps with a floating wick. The illumination obtained from such a fixture must have been truly indirect in nature.

This paper contains some food for thought for the illuminating engineer, for in spite of my remarks, there are other equally or more important considerations involved in this fixture question than pure efficiency.

Mr. C. O. Bond: I was pleased to note the reference to the conservation of vision in connection with this reduction of the brilliancy of light sources. But I would like to ask, have the makers of glassware set any limit for intrinsic brilliancy, and, if so what is the limit? Do you say how many candles per square inch you will go to and then stop at that point? Or do you make it a matter of contrast between this glassware and the background against which it would be placed? This is a point which it would be very desirable for the fixture makers to keep in mind. They might agree among themselves and at the same time keep within the confines of what is considered esthetic.

Mr. T. H. Amrine: Regarding the type of fixtures placed in homes, I was in a residence last night where everything was of the highest type and every room was equipped with mission furniture. The week before a fixture salesman had sold the people a very beautiful highly polished brass fixture equipped with very cheap glass. If the fixture manufacturer had been educated up even to the period proposition, such a fixture as that never would have been placed in that home.

Mr. C. O. Bond: Among gas companies it has been the practise, where lighting fixtures were to be placed in houses, to state certain safety requirements that had to be met by those fixtures before the gas companies would turn on the gas. Following out this thought I believe the day will come when there will be legislation for the protection of the organ of vision just as there is now legislation in protection of our ears from undue noises. You can see signs near hospitals strictly forbidding in the neighborhood of those hospitals the making of unusual noises. We find also that the olfactory nerve is protected; you can not go into a residence section and start a business or a factory that produces a stench. Eventually it will be the same with the eye. And when that day comes we can cope with the man who would install cheap glassware.

Mr. M. Luckiesh: This paper points out the intimate relation that must exist between the fixture designer and the lighting practitioner. This relation must be more fully recognized by the designer than it generally is to-day. There must also be more co-operation between the decorator and the lighting expert and the latter must become an artist in some small degree at least. There are great opportunities in lighting practise along esthetic lines and I look for much development in the artistic use of light.

The fixture is always between the light source and the eye and in such a position it plays a very important part in lighting practise. We must not overlook the consumer's position, however. Upon whom must he depend in selecting his lighting units? He is not a lighting expert nor can he often afford to obtain the advice of one. He must depend upon his own judgment, the manufacturer's reputation or the salesman's recommendations. He likely is largely influenced by the latter and, therefore, the

salesman must know the principles of good lighting from the utilitarian side as well as the esthetic side. That is to say, a large part of illuminating practise is in the hands of the salesman. Many fixture salesmen will talk very definitely about this or that "period" with little consideration of the welfare of the eye. A duty devolving upon the fixture manufacturer lies in the education of those who sell the product to the consumer. Of course the Illuminating Engineering Society is as a whole an educational body which is doing its share along this line. It should consider as one of its special duties the education of the salesman in the principles of good lighting. If the salesman is taught to recognize these principles he will naturally lay stress upon an article which is not only beautiful but useful as well. And this brings up the question as to what is beautiful. Look at a vast number of reading lamps and you will find relatively few that are of utilitarian value. If a lamp is meant for reading purposes it is questionable whether it is beautiful, unless it fulfills its purpose, for beauty is truth.

I believe the illuminating engineer will make his mark by close attention to the esthetic use of light bearing in mind also the conservation of vision. I have heard it expressed that decoration involves only composition, color, and congruity. This can be the law of the illuminating engineer when considering the esthetics of lighting if he includes in the word congruity the utilitarian value of the installation. I want to impress my very strong opinion that the esthetic side of lighting is of very high importance in interiors. We must combine esthetics with the utilitarian principles with which we as a rule are more familiar.

Mr. Bond raised the question as to what constitutes glare. As yet we do not know what it is but fortunately we have learned to recognize it and therefore can avoid it. Glare is a complicated phenomenon. That it is largely due to excessive illumination on the eye can be refuted by standing close to a window and looking out upon a large sky area. We experience little discomfort yet the eye may be illuminated to an intensity of several hundred foot-candles. If the interior wall is dark we experience discomfort when we view the window at some distance. This and many other instances indicates that excessive contrast is a large factor

in producing glare. A bare tungsten lamp viewed against a dark background causes much annoyance, yet when viewed against a bright sky it is almost unnoticed. This shows that the intrinsic brightness is not largely responsible for glare. I am strongly of the opinion that contrast plays the most important part but of course this involves in some manner intrinsic brightness, intensity of illumination of the eye, and retinal adaption.

MR. A. L. POWELL: Mr. Luckiesh has said quite a little of what I had in mind, but I feel so strongly on the question of fixtures, that I cannot refrain from saying a few words.

We must have more co-operation between the illuminating engineer, the glassware manufacturer, and the fixture manufacturer. In practise I have had a number of cases in the lighting of some very beautiful homes, in fact a number of millionaires' residences. On inquiring of the owner as to whether the lighting is planned as to location of outlets, type of equipment, etc., one is informed that all the fixtures are in and the only information desired is the size and type of lamp to use. Further inquiry as to who designed the installation reveals that it was left in the hands of the fixture manufacturer. The average individual seems to have the opinion that if the order for fixtures is placed with a high priced fixture house, that is all there is to do, as regards the lighting.

Examination of the house reveals the result. The fixtures in themselves are very elegant, correct in period, and of splendid metal working; but the equipment of glassware is really abominable. Roughed inside crystal shades and other cheap types of glassware abound.

Now from the standpoint of the illuminating engineer, the quality of the glassware is a most important item, for this controls the diffusion and distribution of the light. In the cases mentioned, considerable sums have been expended for the fixtures, but often the glassware used costs but a few cents a piece.

The fixture men, as Mr. Luckiesh said, place the period question far ahead of diffusion, distribution of light and protection of the eyes. There is no question that the artistic element is a very important factor, and the period must be correct, but we can have all these and also the protection of the eye and

desired diffusion and distribution of light, because there is such a variety of good glassware on the market from which to make a choice; glassware can be secured which will not only harmonize with the fixture, but give all these good qualities. One cannot understand why it is that quite a number of the fixture manufacturers—I will not say all—do not seem to realize that there is this good glassware available. They should get in touch with the glass people and get something which is good from all points of view to market with their fixtures.

Mr. F. J. Blaschke (In reply): There has been a great deal of discussion about the different periods. We all know that periods are recognized in connection with the furniture business as in many other lines of industry, and I can not uderstand why anyone should maintain that they should not be recognized in the design of fixtures. Of course periods are not accurately limited although we are sometimes led to believe so. Just a few days ago I saw a reference to the periods of one of the Louis' that was said to end in 1543. I do not know just where the author found the authority for the accurate limitation. I do not believe the definition can be made very accurately, but I do think that there are a number of very clearly defined periods in the history of the world in which certain distinct types of furniture and other decorations are prominent.

In regard to the origin of indirect lighting, the incident mentioned by Mr. Rowe was decidedly before my time, and I had not thought of anything of that nature. The idea in mind in writing the paper was that it is only recently that indirect lighting has been recognized as such. The proposition of indirect lighting may have been attempted in earlier days, but it has never been worked out satisfactorily until within the last ten years.

There is certainly need for co-operation between the illuminating engineer and the fixture manufacturer. No one realizes it more than the fixture manufacturer himself. I believe the trouble encountered is due largely to the fact that there are a large number of small manufacturers of fixtures, no one of them having any clear idea of illuminating engineering or any desire at all to consider his problems from that standpoint. What the small manufacturer is after is as much profit as he can make

with the least trouble and I believe that this is the principal cause of the difficulty. Just a few days ago I was reading an article in one of the technical journals in which this same point was brought up. I think the article discussed the problem of the consumer who goes into a fixture establishment to buy something to use in his home; his wants are attended to by some underpaid clerk who had no more idea of what the customer should have than any man on the street. Such conditions offer great opportunities for some good missionary work by the Illuminating Engineering Society. The person who is the connecting link between the consumer and the maufacturer should know more about his business than he ordinarily does. That point, I believe, will be admitted by every one present.

The question of adapting the glassware to the fixture and vice versa is a very serious problem. Oftentimes the fixture maker is at fault because he finds that after spending a great deal of time and money in designing and making a fixture the cost has been raised to such a point that he must retrench somewhere, and he does it by using a cheap quality of glass that should not be used with the fixture that he has produced. The fixture manufacturer and the fixture dealer should first be educated to know what is correct, and the ideal condition will be brought about only when the consumer also becomes enlightened.

MR. WARD HARRISON: This paper emphasizes the growing importance of semi-indirect illumination. As I listened to it I recalled to my mind the old upright gas burner with its plain opal globe which three or four years ago was ridiculed as being the most inefficient and undesirable form of illumination imaginable; now it begins to look as though the people who designed these units were really making the best use of the material available at the time.

A PHOTOMETRIC ANALYSIS OF DIFFUSING GLASSWARE WITH VARYING INDIRECT COMPONENT.*

E. B. ROWE AND H. H. MAGDSICK.

Synopsis: In spite of the rapidly increasing use of glass bowls in which a considerable part of the total light is utilized indirectly with a smaller proportion of direct transmitted light, very little photometric data on the performance of these units seems to be available. The authors have therefore made a photometric study of the effect on the shape of the distribution curve and on the proportion of direct and indirect light due to variations in the contour of the glassware, the number and arrangement of lamps and some of the different kinds of diffusing glass which are now in commercial use. For the range of conditions covered by these tests, it was found: first, that the position of the lamp with reference to the bowl is an important factor in determining the distribution of light; second, that the results secured with various lamp arrangements are similar except in the case of a single pendant lamp, which gives a more extensive distribution than other arrangements; third, that the variation in total absorption of the various glasses is slight, but that the distributions secured differ widely; fourth, that the principal effect of variation in contour is to distribute a relatively larger proportion of the light in the 0°-60° and the 120°-180° zones as the diameter of a bowl is increased relative to its depth; fifth, that the appearance of the units is satisfactory in practically all instances.

INTRODUCTION.

In a recent paper presented by Mr. V. R. Lansingh before this Society, the relative performance of the more usual types of enclosing glassware is shown graphically and in terms of zonal flux.[1] Such data are unquestionably of value and their publication records in the TRANSACTIONS information that cannot readily be obtained elsewhere. In the course of their everyday work, the authors have felt the need of similar data on the so-called "semi-indirect" type of glassware, which is gaining in popular favor at the present time. The amount of published data of this kind is small as yet and while the selection of these units is usually based primarily upon appearance, it is felt that some

* A paper read at a meeting of the Pittsburgh Section of the Illuminating Engineering Society, January 16, 1914.

[1] V. R. Lansingh, "The Characteristics of Enclosing Glassware," TRANS. I. E. S. Vol. VIII, p. 447.

knowledge of the engineering features will be welcomed by those who design lighting systems for the classes of service where this method of illumination is applicable.

The study of this type of unit was approached with some trepidation owing to the almost infinite number of combinations which are available. The kinds of glass in which the bowls are being made are numerous, the type of fixture and number and arrangement of lamps can be varied throughout a wide range and the number of shapes and designs is increasing rapidly. However, it was felt that a few combinations might be selected for test and results obtained which would not only bring out certain characteristics of this type of unit not now fully recognized, but which, after a careful study, might be found to be suggestive of the performance characteristics to be expected from combinations other than those actually tested.

NATURE OF MATERIAL TESTED.

One ever-present difficulty in studying and classifying data of this nature is the differentiation of the so-called "opal" glasses. On numerous occasions during the past few years it has been emphasized in papers presented before this Society that no entirely practicable and consistent classification for the various commercial types of such glassware is available nor has yet even been proposed. The trade name of any particular glass is undoubtedly the best identification at present, but a rigid definition which would enable one who is reasonably familiar with illuminating glassware to grasp the fundamental characteristics of any unit without inspection or detailed description is entirely lacking.

There are numerous methods by which such identification of glass might be made:

First, on the basis of chemical composition. This is obviously impracticable, not only because the glass formulae are not made public, but also because the character of the ware may depend more on manufacturing processes than upon its ingredients.

Second, on the structure of the glass. This could be determined by micro-photographic or other tests.

Third, on diffusion characteristics, that is, the amount and direction of transmitted and reflected light, absorption, etc.

Some study of diffusing glasses along these lines has already been made by Mr. M. Luckiesh.[2] In this investigation the diffusion characteristics of a number of commercial glasses were studied and the applicability of the author's methods in rating glassware according to its diffusion properties was discussed.

Fourth, on the photometric performance of the glass in some standard reflector shape. The relative amounts of transmitted, reflected, and absorbed light could be determined, as well as the distribution of the direct, reflected, and transmitted components.

Fifth, on the basis of appearance by reflected or transmitted light or by both.

In this paper no attempt has been made to identify the different kinds of glasses tested in any rigid manner. Four types of commercial glass were selected and these have merely been designated by letter; their identification is established by the trade names given in the appendix. Their relative transmission can, of course, be determined from the test data, and the diffusion, that is, the appearance when lighted, may be judged somewhat by illustrations A, B, C, D, of Fig. 1. This photograph was taken with a 25-watt lamp in each bowl. The glass of least density, designated as A, is the ordinary roughed-outside, etched or ground glass upon which a design is cut, so that when lighted a characteristic bright spot appears through the roughed portion of the bowl and the lamp filament is visible through the relatively small clear areas of the cut design. Its appearance when lighted is shown in Fig. 1. Unit B is of blown glass of relatively light density. The photograph shows the bowl with glazed inner and outer surfaces as it was first tested. The bowl was then roughed outside and the measurements repeated. As is indicated by the photograph, the diffusion is excellent. The glass marked C is of relatively light density and the outer surface is always depolished. The samples used had a glazed inner surface. As will be noted from the photograph, the diffusion is equal to that of unit B and the transmission is slightly less. The densest glass tested is designated as D. The outer surfaces of the test samples were depolished and the inner surfaces were, with one exception, glazed. As is shown by the photograph and

[2] M. Luckiesh, "Investigation of Diffusing Glassware," *Electrical World*, Nov. 16, 1912.

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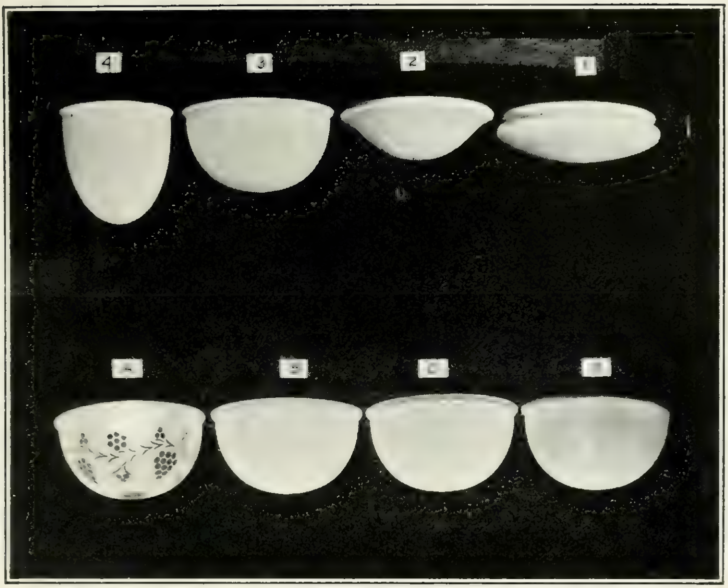


Fig. 1.—Test material. 1-4 : contours. A-D : types of glass.

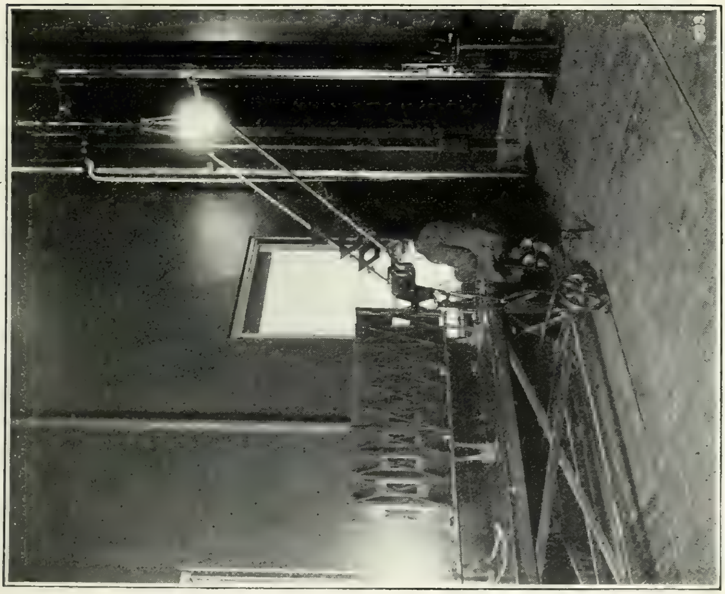


Fig. 2.—Dibdin photometer with fixture and test unit.

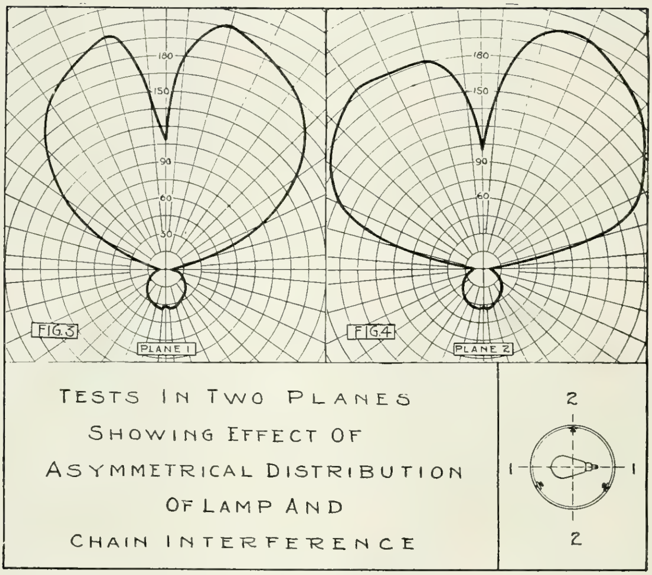


Plate I.—Effect of asymmetrical distribution of lamp and chain interference.

the photometric distribution curves, a satisfactory uniformity of brightness is secured and the relative transmission is low.

TEST PROCEDURE.

Three principal series of tests were undertaken to determine the effect of, first, different lamp arrangements; second, density of glass; third, contour. In addition, investigations were made of the effect of chain interference and asymmetrical distribution from lamps and the variations caused by changes in lamp position with reference to the bowl. The lamp arrangements used, selected to give as nearly as practicable the same total wattage, were as follows: A single 150-watt clear tungsten-filament lamp pendant, the same lamp in an approximately horizontal position, two 100-watt clear tungsten-filament lamps approximately horizontal and three 60-watt clear tungsten-filament lamps approximately horizontal. The four glasses tested were discussed above. Four contours numbered 1, 2, 3, 4, as shown in Fig. 1, were used. The brushed brass fixture employed consisted of three chains with an inside supporting ring 9/16 in. (14.29 mm.) by 5/32 in. (3.97 mm.) in cross section.

In preparing each unit for test it was necessary to adopt some criterion for the lamp positions. The arrangement was adopted as standard which would give, as nearly as possible, a uniform angle of cut-off for the filament center, approximately 13° above the horizontal.

With a single exception, all photometric measurements were made by the engineering department, National Lamp Works of General Electric Company in their newly equipped laboratories at Nela Park. Fig. 2 shows one unit in position on the large Dibdin photometer which was employed in all the tests. Every precaution was taken to secure the highest possible precision in the measurements, which were made by two experienced photometricians using a single set of glassware and lamps with, so far as possible, a constant fixture and support arrangement. All lamps were carefully rated for total light flux previous to the tests.

With the exception of the tests shown in Figs. 4 to 6, inclusive, the data for the distribution curves were obtained by rotating the units, for measurements in the lower hemisphere, and by

readings in a number of planes, for the upper hemisphere. Thus in the case of the one and two horizontal lamp arrangements, tests were made through 360° in three planes and the average curve was obtained. The measurement of the intensities in the upper hemisphere could not be made satisfactorily with the unit rotating because of the flicker caused by the chains.

TEST RESULTS.

The data secured are shown graphically on the accompanying plates. An attempt has been made to include in each case all information necessary for a complete explanation of the test conditions. The sketches of the bowls and lamps are drawn to scale. To facilitate ready comparison, the distribution curves are plotted to a uniform candle-power scale with absolute values that would be obtained with light sources giving a total of 1,000 lumens when bare. The different units may therefore be compared without reference to the size or total wattage of the lamps employed. The actual candle-power values for a given combination may be found by multiplying by the ratio of the actual lumens of the lamps used to 1,000 lumens; thus, in the case of two 100-watt lamps giving 962 lumens each, the actual intensities are 1.924 times the value shown by the curve. The zonal flux data are given in percentages of bare lamp flux, rather than that of the complete unit, in order that the absolute efficiencies of the units may be shown.

The variation of light distribution in different vertical planes is indicated by Plate I., which shows the maximum changes. The results are those secured with contour 2, glass D. The effect of chain interference in plane 2, as shown by Fig. 4, is approximately constant for all the units tested. The variation caused by asymmetrical distribution from lamps, Fig. 3, is materially reduced when three lamps are used and disappears entirely with the use of the single pendant and two horizontal lamp arrangements. The difference between planes 1-1 and 2-2 is more marked than that between the halves of either. The same condition holds true for two horizontal lamps but not for three, nor for the pendant lamp. Aside from the shadows cast by the chains, however, the ceiling appears to be approximately symmetrically illuminated by the various units.

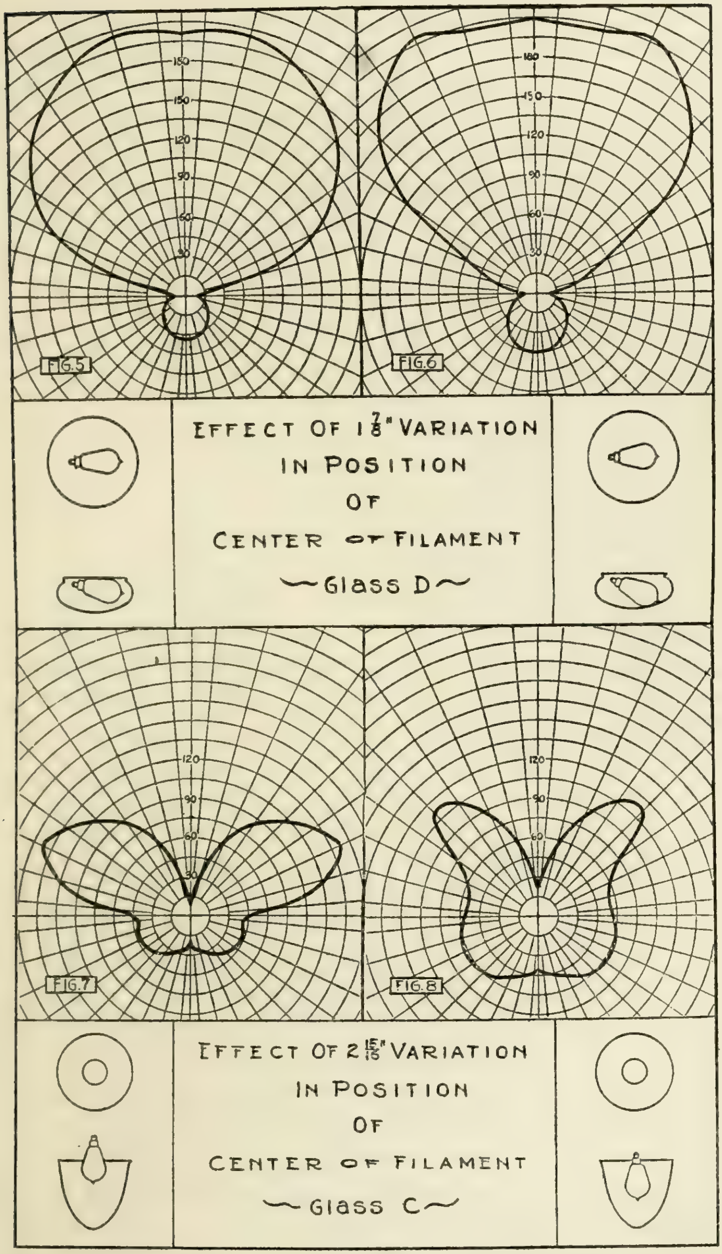


Plate II.—Effect of changing the vertical position of the lamp.

The *effect of lamp position with reference to the bowl* is shown in Plates II and III. Figs. 5 and 6 give the results of a test on a bowl of glass D in a contour that would be classed between 1 and 3. This is the one instance in which test data have been included which were previously available. The photometer of Fig. 2 had, however, been used in making the measurements. Figs. 7 and 8 were secured from a bowl of contour 4, glass C, with a single pendant lamp. Figs. 7a and 8a show the corresponding effect with the dense glass D. In the case of both

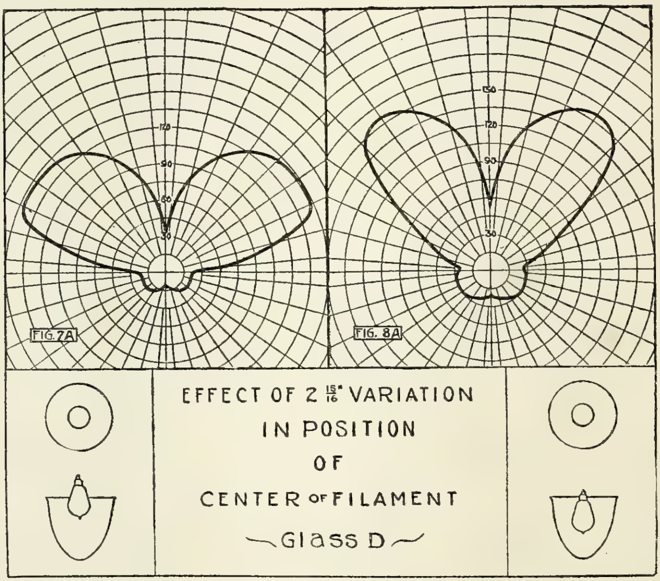


Plate III.—Effect of changing the vertical position of the lamp.

units the lowering of the lamp in the bowl materially increases the lower hemispherical flux and concentrates that in the upper hemisphere at the higher angles. The low position of the lamp therefore makes possible a higher efficiency in utilizing the light flux. On the other hand, the distribution with the lamp higher is more suitable if it is desired to spread the light from each unit over a large ceiling area. Plates II and III merit special attention; it is believed that the significance of lamp position has not been fully recognized in the past.

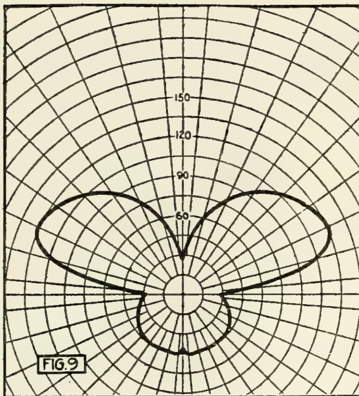
Variation in light distribution due to different lamp arrange-

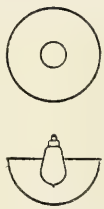
ments was found to be similar for each of two glasses in the two contours tested, 2 and 3, as will be seen from Table 1. The results are, therefore, shown graphically for contour 3 only. Plate IV records the data for glass C and Plate V for glass D. Both show the same characteristic variation; no marked differences in the amount and distribution of the flux in the upper and lower hemispheres appear on either except for the single pendant lamp, which, as would be expected, produces a wider distribution than the other arrangements. One may conclude that the pendant lamp should be considered in the selection of lamp arrangement for contour 3 only when a wide distribution on the ceiling is desired. From the results secured and the data on subsequent plates it would seem that the relative results for other glasses and contours can be predicted fairly accurately.

TABLE 1.—ZONAL FLUX VALUES IN PER CENT. OF BARE LAMP FLUX FOR VARIOUS LAMP COMBINATIONS.

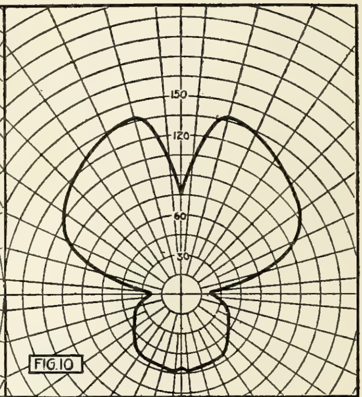
	Per cent. of bare lamp flux				
Zone	0°-60°	0°-90°	90°-180°	120°-180°	0°-180°
Glass C—Contour 3					
1 lamp pendant	13.7	24.3	57.3	30.0	81.6
1 lamp horizontal.....	15.9	26.1	56.3	37.6	82.4
2 lamps horizontal....	14.9	24.5	56.1	37.5	80.6
3 lamps horizontal....	15.0	24.7	58.9	39.3	83.6
Glass D—Contour 3					
1 lamp pendant	6.4	10.6	68.1	41.5	78.7
1 lamp horizontal.....	7.8	12.0	70.3	50.1	82.3
2 lamps horizontal....	7.6	11.5	64.9	47.6	76.4
3 lamps horizontal....	5.8	9.7	68.9	50.0	78.6
Glass C—Contour 2					
1 lamp pendant	15.9	23.9	58.1	36.0	82.0
1 lamp horizontal....	16.5	24.7	61.8	44.8	86.5
2 lamps horizontal....	15.7	23.0	60.3	43.9	83.3
3 lamps horizontal....	15.9	23.1	60.9	44.1	84.0
Glass D—Contour 2					
1 lamp pendant	7.5	11.1	71.3	46.1	82.4
1 lamp horizontal.....	7.8	11.2	73.3	55.3	84.5
2 lamps horizontal....	7.8	11.1	68.0	52.7	79.1
3 lamps horizontal....	7.9	11.4	71.3	53.6	82.7

The study of the *various kinds of glass* was carried out with contour 3 and the single pendant lamp, only. The data are given in Table II and on Plate VI. Glass density produces marked variations in the distribution of the light. It is evident that as the transmission of the "opal" glasses decreases, the absorption increases, although the total range of absorption is only from 16.3 to 21.3 per cent. The denser units, of course, direct a

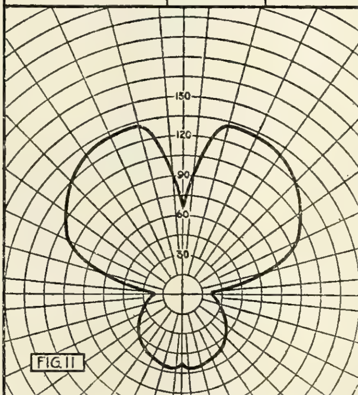




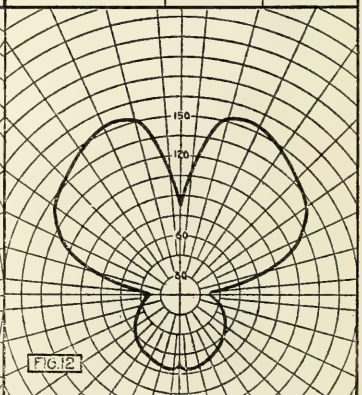
Glass	C
Contour	3
Lamp	1-150 Watt
PER CENT TOTAL LAMP LUMENS	
0°- 60°	13 7
0°- 90°	24.3
120°-180°	30.0
0°-180°	81.6

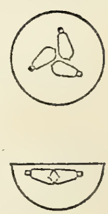


Glass	C
Contour	3
Lamp	1-150 Watt
PER CENT TOTAL LAMP LUMENS	
0°- 60°	15.9
0°- 90°	26.1
120°-180°	37.6
0°-180°	82.4



Glass	C
Contour	3
LAMPS	2-100 Watt
PER CENT TOTAL LAMP LUMENS	
0°-60°	14.9
0°-90°	24.5
120°-180°	37.5
0°-180°	80.6





Glass	C
Contour	3
Lamps	3-60 Watt
PER CENT TOTAL LAMP LUMENS	
0°- 60°	15.0
0°- 90°	24.7
120°-180°	39.3
0°-180°	83.6

Plate IV.—Effect of lamp arrangement—glass C, contour 3.

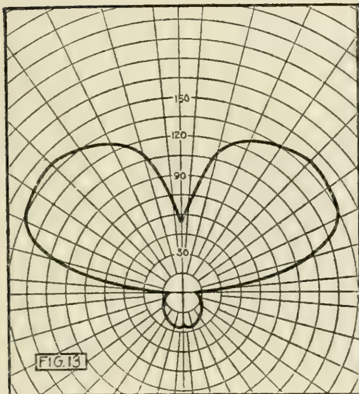
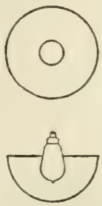


FIG. 13



Glass	D
Contour	3
Lamp	1-150 Watt
PER CENT TOTAL LAMP LUMENS	
0°- 60°	6.4
0°- 90°	10.6
120°-180°	41.5
0°-180°	78.7

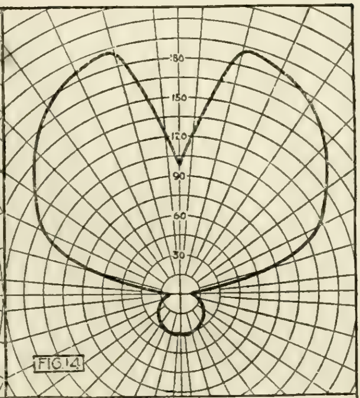


FIG. 14

Glass	D
Contour	3
Lamp	1-150 Watt
PER CENT TOTAL LAMP LUMENS	
0°- 60°	7.8
0°- 90°	12.0
120°-180°	50.1
0°-180°	82.3

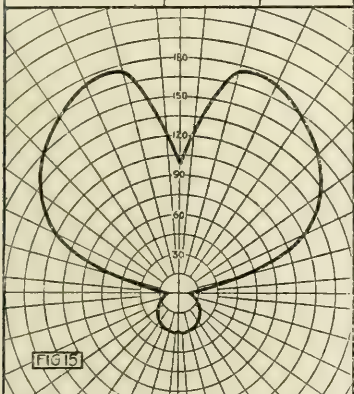
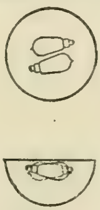


FIG. 15



Glass	D
Contour	3
Lamps	2-100 Watt
PER CENT TOTAL LAMP LUMENS	
0°- 60°	7.6
0°- 90°	11 5
120°-180°	47 6
0°-180°	76.4

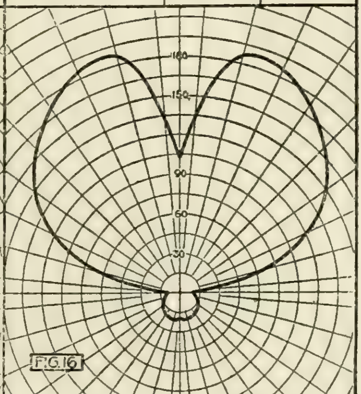


FIG. 16

Glass	D
Contour	3
Lamps	3-60 Watt
PER CENT TOTAL LAMP LUMENS	
0°- 60°	5.8
0°- 90°	9.7
120°-180°	50.0
0°-180°	78.6

Plate V.—Effect of lamp arrangement—glass D, contour 3.

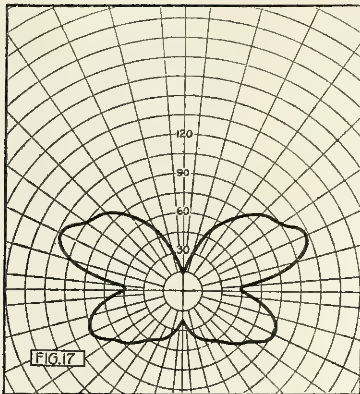
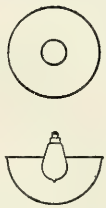


FIG. 17



Glass	A
Contour	3
Lamp	1-150 Watt

PER CENT TOTAL LAMP LUMENS	
0°- 60°	16.0
0°- 90°	37.0
120°-180°	22.1
0°-180°	83 6

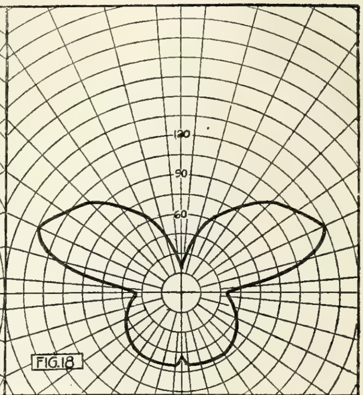
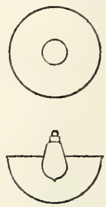


FIG. 18



Glass	B
Contour	3
Lamp	1-150 Watt

PER CENT TOTAL LAMP LUMENS	
0°- 60°	17.0
0°- 90°	29.9
120°-180°	26.9
0°-180°	83.7

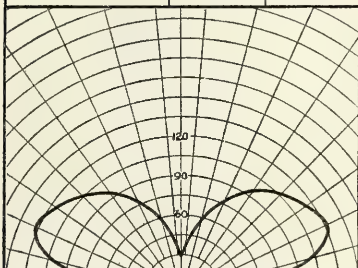
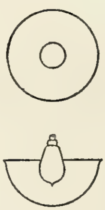


FIG. 19



Glass	C
Contour	3
Lamp	1-150 Watt

PER CENT TOTAL LAMP LUMENS	
0°- 60°	13 7
0°- 90°	24 3
120°-180°	30 0
0°-180°	81 6

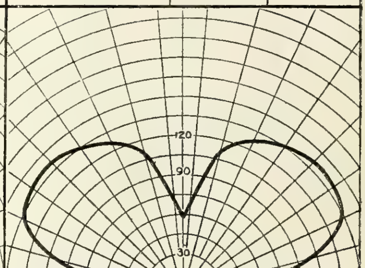
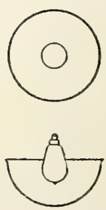


FIG. 20



Glass	D
Contour	3
Lamp	1-150 Watt

PER CENT TOTAL LAMP LUMENS	
0°- 60°	6.4
0°- 90°	10 6
120°-180°	41 5
0°-180°	78 7

Plate VI.—Effect of various glasses.

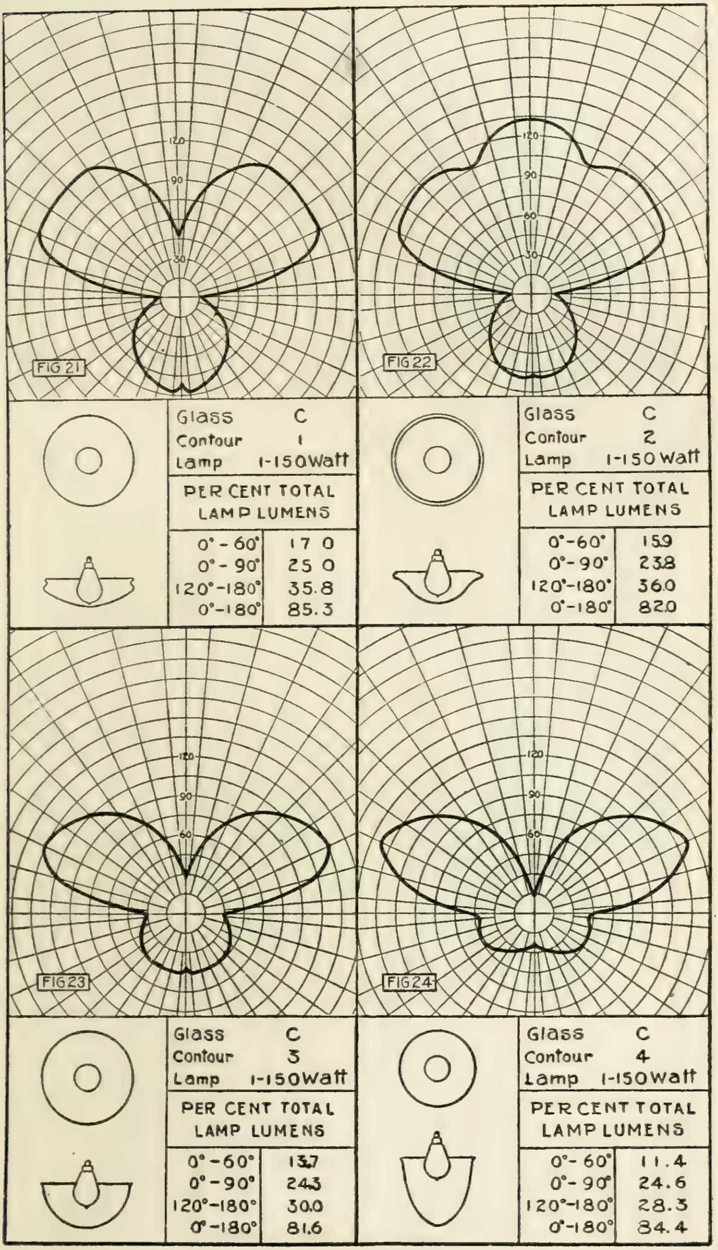
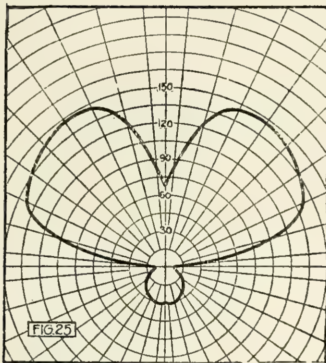
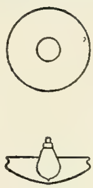
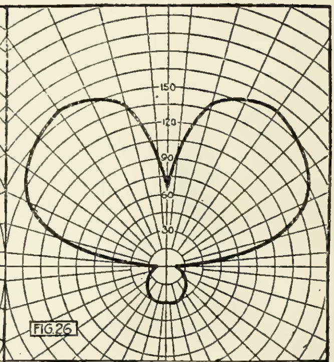


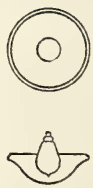
Plate VII.—Effect of contour—glass C.



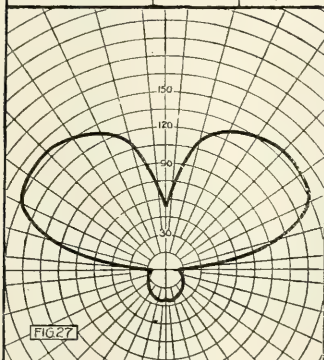


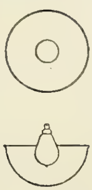
Glass	D
Contour	1
Lamp	1-150 Watt
PER CENT TOTAL LAMP LUMENS	
0°- 60°	7.3
0°- 90°	10.5
120°-180°	43.5
0°-180°	79.0



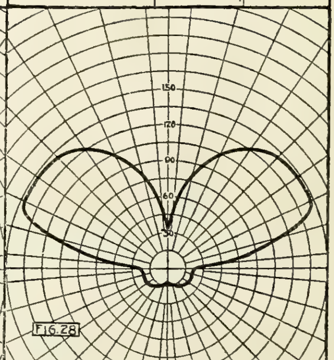


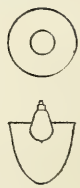
Glass	D
Contour	2
Lamp	1-150 Watt
PER CENT TOTAL LAMP LUMENS	
0°- 60°	7.5
0°- 90°	11.1
120°-180°	46.1
0°-180°	82.4





Glass	D
Contour	3
Lamp	1-150 Watt
PER CENT TOTAL LAMP LUMENS	
0°- 60°	6.4
0°- 90°	10.6
120°-180°	41.5
0°-180°	78.7





Glass	D
Contour	4
Lamp	1-150 Watt
PER CENT TOTAL LAMP LUMENS	
0°- 60°	5.9
0°- 90°	12.6
120°-180°	50.0
0°-180°	77.5

Plate VIII.—Effect of contour—glass D.

larger percentage of light above the horizontal; they also give a more efficient distribution of the light in both hemispheres. Tests on glass B, contour 3, were first made with glazed inner and outer surfaces, as shown in Fig. 18; the bowl was then roughed outside and the tests repeated. The effect of the depolishing was practically negligible both on the quantity and distribution of the flux. The zonal flux values for all glasses are given in Table II. Comparison of these data with those of Tables I and III suggests the relative performance of each kind of glass in the other contours and lamp arrangements.

TABLE II.—ZONAL FLUX VALUES IN PER CENT. OF BARE LAMP FLUX FOR VARIOUS GLASSES IN CONTOUR 3 WITH PENDANT LAMP.

Zone	Per cent. of bare lamp flux				
	0°-60°	0°-90°	90°-180°	120°-180°	0°-180°
Glass A	16.0	37.0	46.6	22.1	83.6
Glass B—glazed	17.0	29.9	53.8	26.9	83.7
Glass B—depolished outside	16.2	28.7	53.6	27.3	82.3
Glass C	13.7	24.3	57.3	30.0	81.6
Glass D	6.4	10.6	68.1	41.5	78.7

TABLE III.—ZONAL FLUX VALUES IN PER CENT. OF BARE LAMP FLUX FOR VARIOUS CONTOURS WITH PENDANT LAMP.

Zone	Per cent. of bare lamp flux				
	0°-60°	0°-90°	90°-180°	120°-180°	0°-180°
Glass C					
Contour 1	17.0	25.0	60.3	35.8	85.3
Contour 2	15.9	23.9	58.1	36.0	82.0
Contour 3	13.7	24.3	57.3	30.0	81.6
Contour 4	11.4	24.6	59.8	28.3	84.4
Glass D					
Contour 1	7.3	10.5	68.5	43.5	79.0
Contour 2	7.5	11.1	71.3	46.1	82.4
Contour 3	6.4	10.6	68.1	41.5	78.7
Contour 4	5.9	12.6	64.9	36.9	77.5

Tests were made with two glasses and one lamp arrangement to determine the *effect of contour on light distribution.* Table III and Plates VII and VIII show the results. The principal effect with both glasses is seen to be an increase in the candle-power in the 0° to 60° and 120° to 180° zones as the depth of the bowl is decreased relative to the diameter; this would be expected from a study of the position of the lamp with reference to the bowl. The effect on the distribution in both hemispheres is, of course, more pronounced in the case of the lighter density units. The high intensity directly above the unit in Fig. 22 is caused by specular reflection from the surface of the bowl. This partic-

ular combination was the only one tested in which the distribution curve was materially distorted as a result of such reflection. The effect of contour in the case of other glasses and lamp arrangements may be judged from a study of the preceding tables and plates.

Inspection of the various units showed the *diffusion* to be excellent in all cases except with glass A. Shadows cast on the bowls by the sockets were noted in the following instances only:

Glass	Contour	Lamps	Shadow
C	3	1 horizontal	Very slight
C	3	3 horizontal	Very slight
C	2	2 horizontal	Very slight
D	2	2 horizontal	Very slight
C	2	1 horizontal	Slight
D	2	3 horizontal	Slight
C	2	3 horizontal	Marked
D	2	1 horizontal	Marked

In no case did the shadows seriously detract from the appearance of the unit.

CONCLUSIONS.

For the range of conditions covered by this investigation it appears that:

(1) Appreciably non-symmetrical distributions result with one or two lamps in the horizontal position but this does not seriously affect the appearance of the ceiling nor the illumination produced.

(2) The distribution is materially affected by changes in the position of the lamps with reference to the bowl.

(3) With a given contour, the various lamp arrangements give practically the same proportions of light above and below the horizontal and the distribution in each hemisphere is similar except in the case of the single pendant lamp, which gives a more extensive distribution above the horizontal. The latter unit would therefore be expected to show a somewhat lower utilization efficiency than the other arrangements but would be more useful where it is desired to distribute the light over a considerable ceiling area.

(4) The variation of light distribution with different glasses is shown to be considerable; the ratio of light above the horizontal to that below the horizontal ranges, in the samples tested, from 1.26 for the least dense sample to 6.4 for the most dense.

The total absorption in the contour used averages 18 per cent.; the variation is 5 per cent.

(5) The effect of contour may be summed up by the statement that the proportion of light in the upper and lower hemispheres is practically constant but with the shallower bowls a larger percentage of light is distributed in the 0°-60° and 120°-180° zones than with the deeper ones; hence the former would, in general, be expected to show higher utilization efficiencies.

(6) The appearance of the units from the standpoint of diffusion and shadow, seems usually to be most satisfactory in the case of a single pendant lamp. The two horizontal lamps also give excellent results and in no case give marked shadows, while in a few types of glassware the three and one horizontal lamp arrangements produce noticeable shadows.

The authors desire to acknowledge the assistance of Mr. W. J. Cady in conducting the tests and arranging the data.

APPENDIX.

TEST MATERIAL.

Designation in paper: Contour	Designation in paper: Glass	Trade name and designation[1]	Maximum diameter inches	Depth inches	Outer surface	Inner surface
1	C	1209-17″ Veluria 63	17	5	Depolished	Glazed
	D	1209-17″ Calla 63	17	5	Depolished	Glazed
2	C	1215-16″ Veluria 64	16	5	Depolished	Glazed
	D	1215-16″ Calla 64	16	5	Depolished	Glazed
3	A	380-16″ Clear cut R-98, 4B				Partially depolished
	B	380-16″ Druid	16	8	Rough	Glazed
	B	380-16″ Druid	16	8	Glazed	Glazed
	C	380-16″ Veluria	16	8	Depolished	Glazed
	D	380-16″ Calla 62	16	8	Depolished	Glazed
4	C	1276-12″ Veluria	12	11½	Depolished	Glazed
	D	1276-12″ Calla	12	11½	Depolished	Glazed

DISCUSSION.

MR. A. L. POWELL: This paper is a most desirable contribution to our TRANSACTIONS. Test data of this nature is extremely useful to the practising engineer, who can apply the results to any similar equipment which is being used.

Speaking of semi-indirect units, we in our office have found one type quite convenient for use. Of course, we recommend the one-piece pressed, or blown white, or opalescent glass bowl

[1] Catalog of Holophane Works of General Electric Company.

very frequently, but often a fixture made up of several sections is very suitable. These sections can be bent into any contour desired; and since the opal is dense, it has quite a directional effect, so that with any given condition, one can obtain the desired distribution. Another feature of this type of unit which warrants its use, is the fact that we can only secure one-piece bowls up to say 30 inches (0.76 m.) in diameter; mechanical difficulties prevent the making of an extreme size such as might be needed to light a large church or assembly room. With leaded glass a fixture can be built five or six feet, (1.52 m. or 1.83 m.) in diameter, and made to accommodate any size of electric incandescent lamp up to, say 2,000 watts. This keeps the number of outlets down to a few and at the same time gives good distribution and makes for a pleasing appearance.

I believe the statement on the tenth page of the paper, reading in part, "the pendant lamp should be considered in the selection of lamp arrangement only when a wide distribution on the ceiling is desired" should be qualified to apply only to the shallow bowl, for with the deep bowl and with the pendant lamp hung fairly low, a relatively narrow distribution is obtained.

Mr. S. G. Hibben: I would like to call attention to the illumination from two identical shapes of bowls of approximately the contour as shown in the figures, but of different glass, and hung at two different distances from the ceiling in typical office rooms.

The room of Fig. A, is about 21 feet (6.40 m.) by 14 feet,, (4.26 m.) and the height of the ceiling above the floor is about 10 feet (3.04 m.). The color of the ceiling is the same as the color of the walls—medium light olive green The upper full-line curve of this figure shows the distribution from the bowl of medium-density glass in the low position, that is, 32 inches (0.81 m.) from the ceiling to the rim of the bowl. The effect of raising this bowl 10 inches (25.4 cm.) is to reduce the illumination beneath, as the dotted line shows

Now note the results from the dense (opal) bowl of the same contour, and with the same lamp, *viz.,* one 100-watt tungsten. This dense bowl in both high and low positions gave practically the same distribution, as shown by the lowest full-line curve, Fig. A.

That brings out a point that is important when considering the relative effects of the transmitted light through the bowl, and the effects that come from the ceiling reflection. The explanation for the fact that a change in the position of the heavy-density bowl has very little effect on the illumination intensities perhaps would be that as the heavy-density bowl is raised from the floor, the illumination beneath the unit (due chiefly to the transmission through the glass) would naturally decrease. But as this bowl is raised there would be another effect, consisting in the more efficient reflection from the ceiling surface, (due to the light

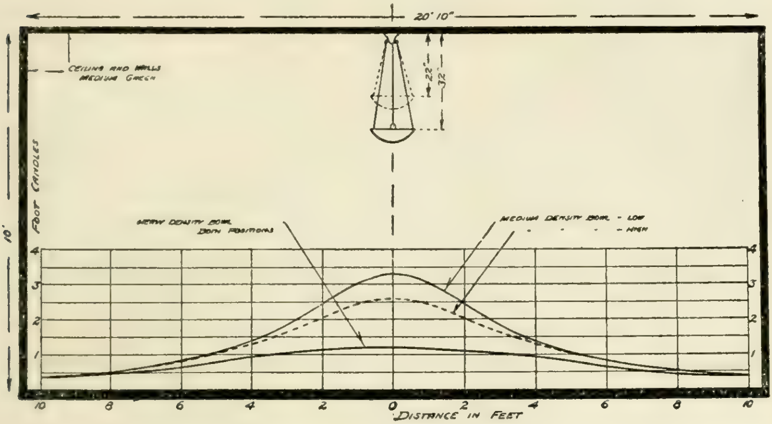


Fig. A.—Distribution of illumination in a medium green room.

striking this ceiling that formerly went to the upper parts of the walls, and to a better angle of incidence on the ceiling) so that by one of these effects opposing the other, there results practically no change under these or similar conditions.

In Fig. B we may note test results where all conditions were similar to those of Fig. A, except that this room was of a distinctly different color. Here we have a cream colored ceiling and light yellow walls. The room was not so long, but all other arrangements were the same. The illumination intensities are much higher, of course, due to the increased efficiency of reflection or diffusion from the light colored interior. The medium-density bowl gives results not unlike those of Fig. A, when placed in the high and low positions, but note what effect these positions have when the heavy-density bowl is used. Placed low, it gives less

illumination than when it is high, showing that the reflection from the ceiling is more efficient in its high position, and that furthermore the component of the illumination that comes from the ceiling is relatively more important, and more than counter-

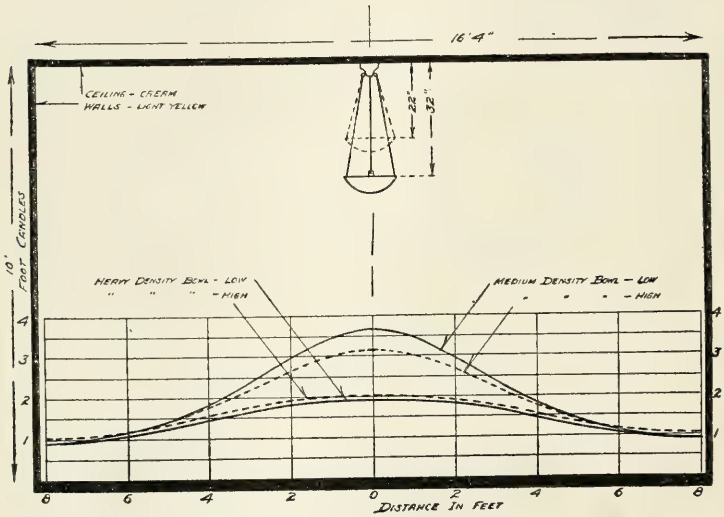


Fig. B.—Distribution of illumination in a light yellow room.

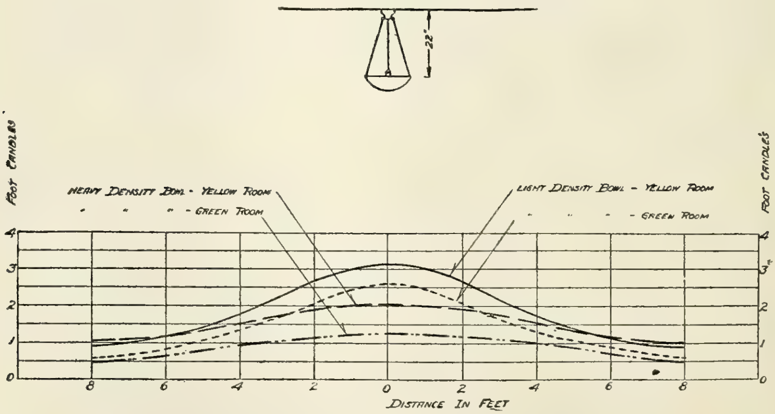


Fig. C.—Comparisons of illumination as in different colored rooms.

acts the component of transmitted light. This is a very curious point, and indicates that there is a great deal of importance connected with the proper application of these units.

In order to better appreciate the differences that result from

different colored interiors, the results of the Figs. A and B are plotted as in Fig. C. It is apparent that the change of color from yellow to green reduces the illumination by amounts from one-half to one-third. The darkening of the color of interior finish has a greater effect on reducing the illumination from the denser bowl, than it effects the results from the lighter bowl.

J. R. CRAVATH, (communicated): The requirements for diffusing bowls for interior lighting were very clearly set forth in a paper[1] by T. W. Rolph before the society at the 1912 convention. He showed that the direct component in indirect lighting with luminous bowls should not be over 15 per cent. and he gave a typical form of photometric curve for an indirect lighting unit of this kind. The results obtained by Messrs. Rowe and Magdsick show that none of the bowls tested are sufficiently dense to cut down the direct component as much as desirable. As some of these bowls tested are among the densest now made I think the conclusion is obvious that our glass manufacturers should endeavor to make denser bowls with highly polished interior surfaces so as to add to the indirect component and subtract from the direct component where such bowls are used.

MR. T. W. ROLPH: In connection with Mr. Cravath's discussion, the percentage of light in the 60° zone as shown by some of those bowls is so low that under ordinary reflecting conditions of ceiling and walls the percentage of direct component of the illumination probably would be as low as 15 per cent. The densest bowls, those of glass D, show a percentage in the 60° zone varying from 5.8 to 7.8. That reduced to per cent. of direct component of illumination would probably result under favorable conditions in approximately 15 per cent. direct component.

I was interested considerably in Mr. Luckiesh's discussion[2] in regard to contrast. Perhaps one of the most interesting observations which we run across every day illustrating the great effect of contrast is to see a flaming arc lamp by daylight and at night. At night we are much impressed with the intrinsic brilliancy, which is quite objectionable in looking at the arc lamp; but by daylight this is scarcely noticeable, due to the brilliancy of the surroundings.

[1] T. W. Rolph. "The Engineering Principles of Indirect and Semi-indirect Lighting" p. 549. Vol. VII (1912).

[2] See p. 216.

The question of the important factors in determining what illumination conditions are best for the eye is one which is not definitely settled. We know that the conditions which are not good for the eye are conditions of contrast and of a large amount of flux in the eye and of high brilliancy; but we do not know the relative importance of these factors. Mr. Luckiesh considers contrast of great importance.

Under interior illuminating conditions at night the degree of contrast in the surroundings is very much less than under daylight conditions. Therefore the actual brilliancy of the light sources, from the standpoint of obtaining contrast, is of considerable importance. The tendency of lamps is toward greater and greater brilliancy. Consequently it is important to consider density of glassware which is to be used with the lamps, from the standpoint of obtaining desirable contrast or lack of contrast, as well as a desirable amount of light in the eye. I think most of us will agree with Mr. Cravath that the lighter density shown here, the etched glass, is entirely too light in density; it allows too much light to pass through. I think most of us will also agree that the densest glass shown here is satisfactory for the quantities of light which are ordinarily put into a bowl of that nature.

Further data is desirable as to the effect on the eye of installations of bowls between these two densities. Such data would be particularly useful in selecting glassware for the more decorative installations. For installations in which the engineering features should predominate, dense glass is the most desirable.

Mr. E. B. Rowe (In reply): I have just a few comments to make in closing the discussion. In regard to this etched bowl, I can say that there is still a great deal of this kind of glassware being sold and I think its continued sale is fostered most, perhaps, by the fixture people. While these ground glass shades and bowls do not appeal to me personally, I can realize nevertheless, that there are certain classes of installations where their use is not very objectionable. For instance, where a number of lamps of low candle-power are used and where the reflecting surfaces are all light, such as in a drawing-room or a bed-room, their use may be permissible to secure some desired period ef-

fect, such as the Colonial. At the same time, too much of this kind of glass is still being sold to the unsuspecting public by ignorant salesmen, in spite of the fact that there is an almost infinite variety of other glassware available, which is much better in every way.

Mr. Luckiesh simply emphasized the point I brought out about the inability of the consumer to get what he ought to have, the results of which we see everywhere.

In regard to Mr. Powell's reference to the tenth page, I think the statement made there is limited and applies to one contour only.

Mr. Hibben's slides are a valuable contribution to this paper, since they emphasize the fact that under certain conditions, what would otherwise be a semi-indirect unit, would be in reality a direct lighting unit. I think this is brought out by his data in showing the variation with the different color treatment in the two rooms. Approximately the same effect as was secured by raising and lowering the unit, can be secured, I believe, by raising or lowering the lamps in the semi-indirect bowl.

I agree with Mr. Rolph's statement in regard to Mr. Cravath's comment. I think, myself, that this denser glass, identified by D, practically meets the requirements for low degree of transmission as set forth by Mr. Rolph in the paper Mr. Cravath referred to. In fact, I have just within a few days, been reliably informed that Mr. Cravath himself has recently seen an installation of this identical glass, and expressed himself then as being satisfied with it as approaching the limit which he thought desirable. I was told that he considered the illumination from those units was in every way equivalent to that secured from the totally indirect unit having the supplementary transparent bowl to provide a small proportion of direct transmitted light.

The demand on the part of the public seems to have been for a semi-indirect bowl with higher transmission. I have thought recently, however, that there is an increasing appreciation of the dense grades of glass and that the next few years would see an increasing proportion of dense glass bowls going into service. The members of this Society and particularly the fixtures people should certainly foster this tendency.

RAILROAD ILLUMINATING ENGINEERING; TRACK SCALE AND YARD LIGHTING.*

BY H. KIRSCHBERG AND A. C. COTTON

Synopsis: It has already been truly stated that a modern railroad presents to the field of illuminating engineering not only every problem met with in the general field, but also in addition a number of special problems, peculiar in themselves, as a result of the requirements of modern railroad practise. The following paper presents three such problems, which, by reason of their correlation, are included in one exposition. These problems are the lighting of the receiving yard, the classification yard, and the track scale. From the importance of their position in the economy of the road as outlined in the paper, it is evident that a correct lighting layout will produce returns well justified by any expenditure of money to obtain the desired results.

Coincident with the development of illuminating engineering, there arose in railroad circles a conception of its applicability to the manifold problems peculiar to transportation, as a means of not only improving and increasing service and results, but in a multitude of cases, of finally solving a number of problems which hitherto had been satisfied with but only a limited degree of success. Not the least among the conditions to be met with in the field of railroad illuminating engineering are some with which the public does not even come in contact, but which nevertheless are really of vital importance either to their safety in travel or to the railroad as a source of revenue.

It is a well known fact that the main source of revenue to a railroad is its freight haulage, the carrying of passengers in a number of instances in this country being in reality maintained at a loss to be offset by other income. Anything, therefore, which will to any degree assist in the movement or improvement of freight traffic will show a large earning capacity of the road equipment and to that extent improve both the financial

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Fig. 1.—Receiving yard.

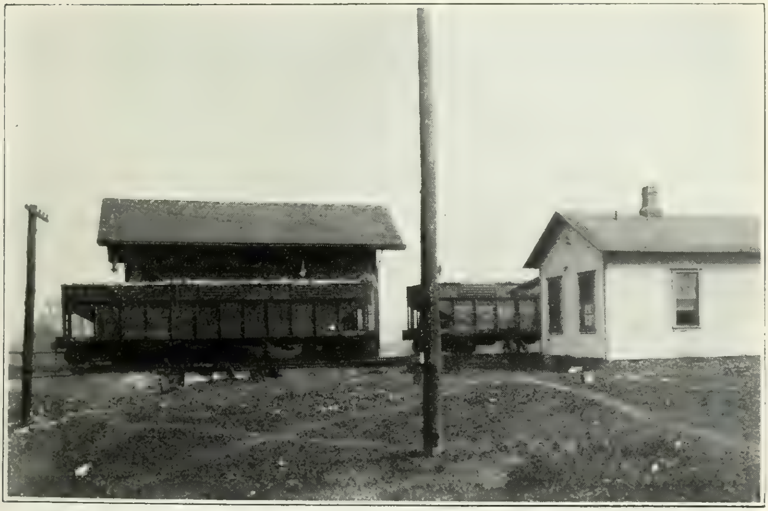

Fig. 3.—Track scale.

Fig. 7.—A modern track scale.

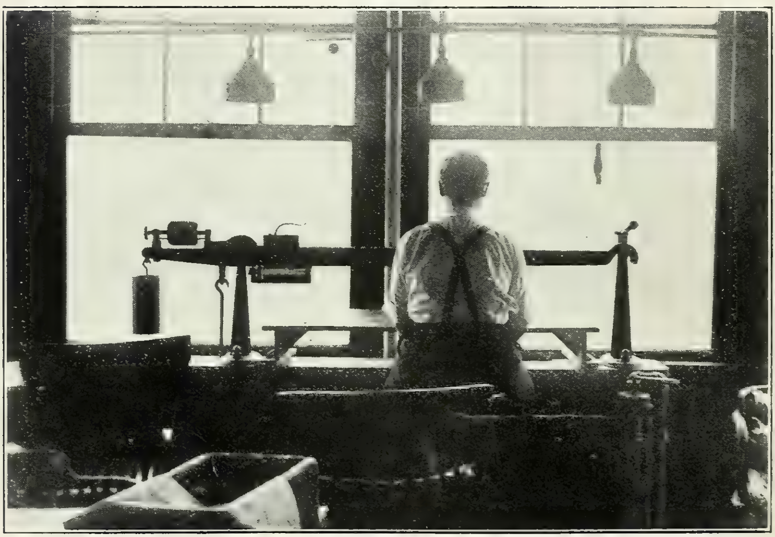

Fig. 9.—Scale house.

condition of the road and its ability to serve the public in every way required of such corporations. This paper has, therefore, been written with a view to showing how, in just one location, an improvement in the lighting condition may produce the beneficial results mentioned before.

As in the body, a railroad may be said to have a number of larger nerve centers or ganglia from which radiate the smaller nerve fibers to exercise their functions in those portions of the body segregated from the main trunk. These centers as applied to freight traffic are the engine house, the receiving and classification yards and the track scale and their auxiliaries; failure of operation in anyone of these might produce a complete tie-up similar in every respect in our similie to paralysis, and which might just as surely creep until the larger nerve centers or terminals are affected, and the entire system becomes paralyzed.

It will be well to explain for the benefit of those not familiar with railroading what a receiving and classification yard and track scale are, for this paper will treat of only these locations. and in the explanation of them and their functions will appear the problems to be met with in the light question. The error, therefore, made by one of our large electrical companies in a suggestion to one of the authors of this paper for lighting a particular yard will then be apparent.

After the freight has been collected at various points along the main line and branches by what are known as way collection freights, or after a train of cars is made up at any one particular point as at a mine or factory, the train enters the receiving yard similar to that shown in Figs. 1 and 9a. These yards are situated at convenient points on the division, with relative positions depending on the direction in which the freight is moving. The whole train is then pushed over the hump and track scale as shown in Fig. 3, whence it proceeds by gravity into the classification yard, shown in Fig. 9b.

Of the many special problems of illumination presented on a railroad, none perhaps is of more importance, from a railroad viewpoint, or capable of more solutions than that of track scale lighting. A modern track scale, as shown in Fig. 7, is a scale from 37 ft. to 83 ft. (11.27 m. to 25.30 m.) in length, and of

300,000 lbs. capacity, built on a concrete foundation, set in the line of track and connected by means of levers to the scale beam in the adjoining scale house. It is used to weigh all freight passing over the road, a large percentage of which is weighed at night, thus necessitating a good lighting system in and around the scale house. Inasmuch as a large portion of railroad revenue depends on freight haulage capacity, and for the reasons that better light around the scales permits a better movement of cars over the scale and through the receiving and classification yards, so increasing that capacity, it is evident that the successful solution of this problem is greatly desired.

The purpose of this exposition of the subject is not so much to offer a solution as it is to present the conditions to be met, leaving the suggestion of type, location and auxiliary fittings of lamps to the individual. It will, therefore, be necessary to explain, as briefly as possible, the operation of weighing, with which explanation the important points needing light will suggest themselves.

The train of cars to be weighed is pushed from the receiving yard to the hump, where each car is cut from the train and allowed to run by gravity down the 2 per cent. grade to and over the scale, thence down the 1.4 per cent. clearance grade to the classification yard to be made up into another train. See Fig. 9b. As the car passes over the scale at a speed at about 2.5 miles an hour, the weighing is done. In addition to the weighing, the number and light weight of the car is read from either the ends or sides of the car, and a record of them made on the manifests in the possession of the weighmaster. The entire operation takes from eight to twelve seconds. It is also necessary to see under the car to a certain extent, in order to determine whether the car is entirely on or partly off the scale. Each car is in charge of a rider, who keeps his position on the car until it has passed over the scale. The conditions to be met in the lighting of the location are, therefore, as follows:

1. Sufficient illumination in the scale house, Fig. 9, with special attention to the scale beam in the bay window, to permit rapid and accurate weighing. At the same time the lamps should be so placed and shielded that none is in the field of vision either

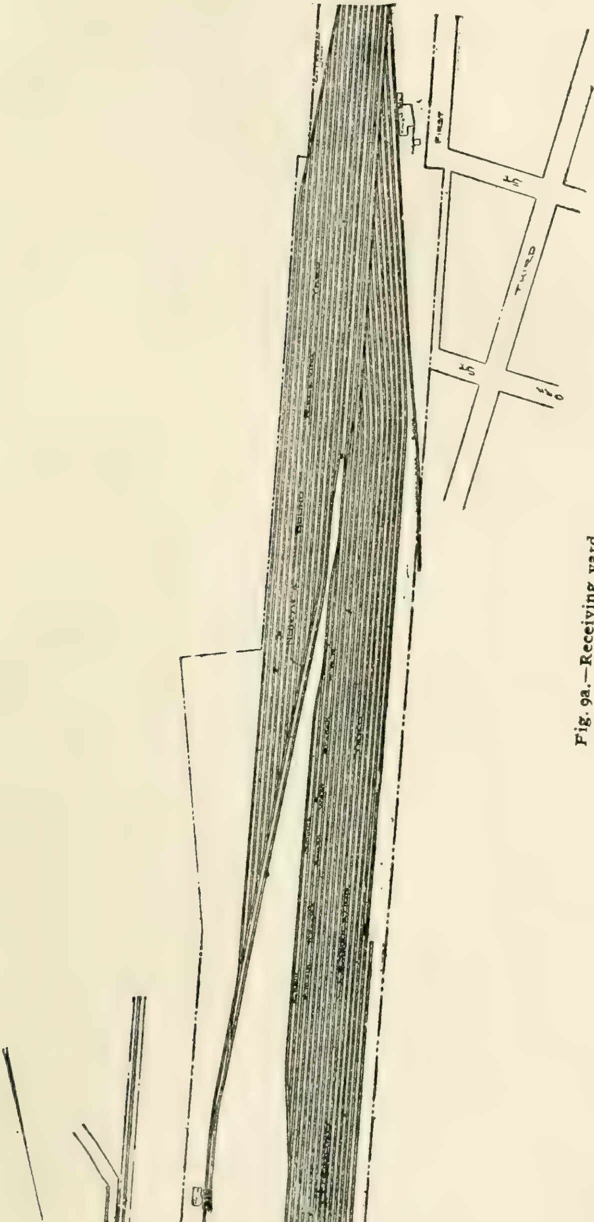

Fig. 9a.—Receiving yard.

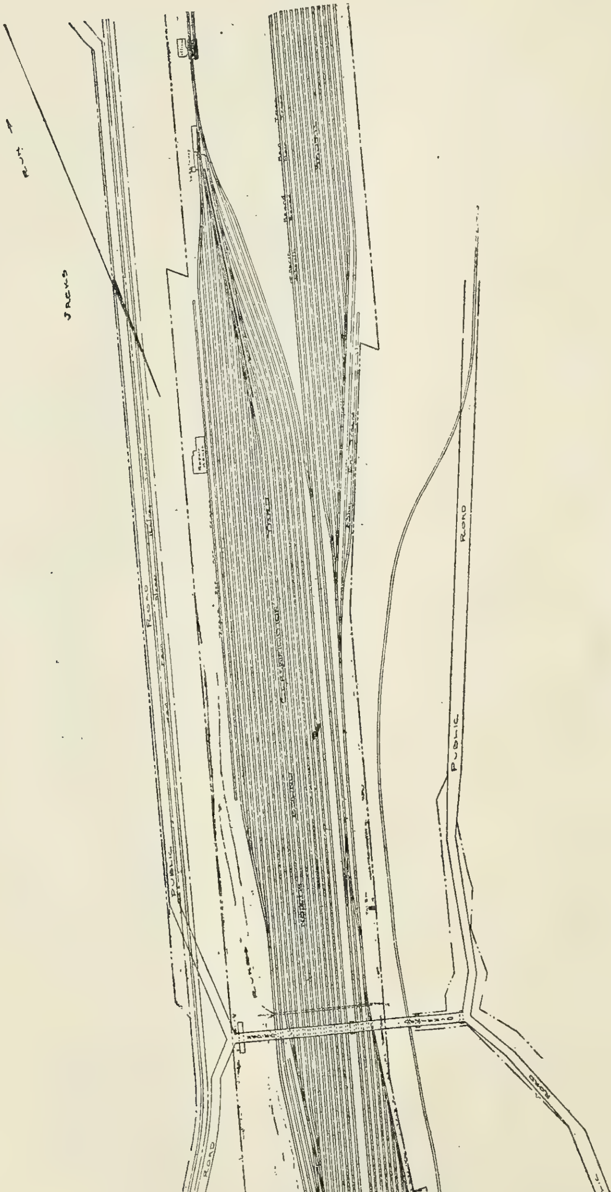

Fig. 9b.—Classification yard.

from the inside or outside of the scale house, and that no reflection of the lamps is seen in the windows, thus making it very difficult to see numbers on the cars outside. If interior lamps are visible from the outside, the glare may be sufficient to prevent good vision around the hump and clearance grades, so resulting in possible accident to riders and car cutters. Fig. 10.

2. Sufficient illumination outside the scale house to permit those inside and those outside to perform the following duties:

Safe cutting of cars at the hump.

Location of car at every point in its movement.

Clear sight of movement of every wheel on to the scale.

Reading of light weights and numbers on ends of approaching cars.

Reading of these weights and numbers on side of car on scale. For this work a clearance of 2 ft 11.5 in. (0.90 m.) is all that is allowed.

Reading of the light weights and numbers on the receding end of car, if not procured during either of the two aforementioned intervals.

Movement of wheels off the scale.

Clear sight of movement of car down the clearance grade in order to safely pass the next car over the scale.

Location of position of car on the clearance grade in order not to bump cars too hard when making up drafts of cars to go down the classification yard.

It is evident that the weighmaster must look from a well lighted room into an illuminated open space with a dark background in order to work; also that the riders are continually moving from a well lighted zone into one with a very low intensity of illumination. Glare in such cases is productive of not only danger to individuals, but also possible damage to equipment and loss of time and money. It would assuredly not be correct to use the general yard lighting system for lighting the exterior, for the reason that light is needed at the scale sometime before the yard lighting is necessary. All scale lamps should, therefore, be on a separate control. With the low height of roof, the small roof overhang, and the narrow space between the side of the car and the scale house window, the problem of placing units of

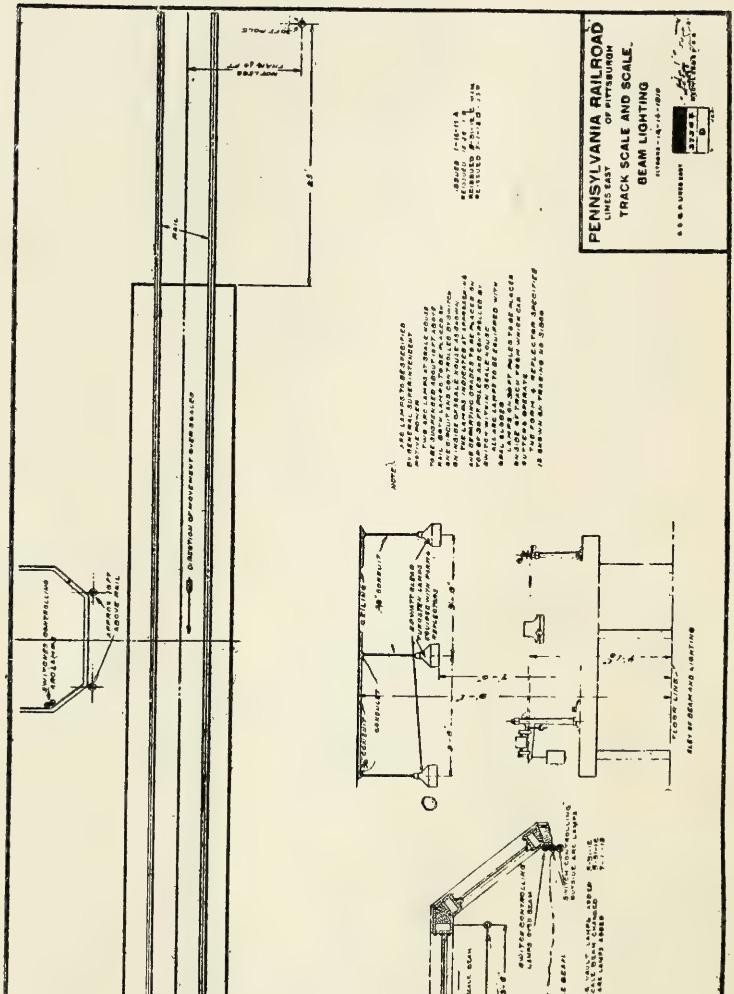

Fig. 10.—Plan of track scale.

large enough capacity and sufficiently low intrinsic brilliancy to do the work is not a very simple proposition. The outside lamps should by no means be visible to the weighmaster.

In locations where an office building, as shown in Fig. 7, is in use in addition to the scale house, the entire front of the building is available for the placing of lamps, thus offering another solution to the problem. This is shown in Fig. 11.

The only standard portion of the building, however, is the scale house bay window and its scale beam as shown. Within the scale house proper may be placed one or more desks, filing cabinets, letter press, wash basin and other furniture and fixtures found in the modern office. An illumination scheme to provide for this additional portion of the office, however, must be somewhat different from the usual office lighting layout to obviate the possibility of imperfect vision both inside and outside of the scale house.

There is, no doubt, a number of methods of obtaining the desired results, but inasmuch as an engineer is one who is supposed to do for one dollar what anyone else can do for two dollars, it is evident that the cheapest and at the same time equally reliable and successful solution is the only one deserving of the appellation of illuminating engineering

The location of the neighboring lighting units, such as may be used for yard or office lighting, will, of course, affect the efficiency of the scale lighting installation. Each case, therefore, contains some feature not found in other cases, for which it is evident that a study of local conditions for each scale is necessary. Track scales often being located at points somewhat distant from power plants, the electrical conditions usually furnish an alternating current, in which case the choice of efficient lighting units and desired distribution of light is narrowed still further than under other conditions.

It is apparent, therefore, that considering all the conditions to be met and while attempting to light the scale and its surroundings inexpensively and efficiently, a study and solution of the problem of track scale lighting draws upon the illuminating engineer not only for a thorough knowledge of illuminants and their particular qualities, but also for a fair amount of ingenuity in

their use to obtain the best results. Naturally, with so many variations in scale length, and the form of energy available, surroundings, etc., it is very difficult and well nigh impossible to lay out a standard scheme for all scales. Were such possible, the solution of the problem would be merely the question of several trials. The individuality of each case, however, is so strong that experienced judgment combined with knowledge, is the only basis upon which to work.

One of the prime justifications for the services of an illuminating engineer on a railroad, at least from a railroad viewpoint, is his ability to save expenses. It is indeed to be regretted that a consideration of the saving accruing from a correct illumination layout usually applies to only the direct saving in either initial cost, energy consumption or maintenance cost. The ultimate results, which are productive of not only a saving of money and energy, but also an improvement of quality and quantity of work turned out with a betterment of conditions in general, are seldom given the attention that would be expected from such far-seeing corporations as railroads. The additional savings, whether of life or of money, ensuing from safer conditions and the multitude of indirect beneficial results are quite often not even traced to their correct sources. It may be truly said that on railroads in general good lighting is conspicuous by its absence. The importance of any piece of apparatus is usually accentuated by its accidental failure to work at which time the saving in expense due to its successful operation assumes an unexpected prominence. The foregoing, applied to lighting on a railroad, is most particularly and forcibly true in the case of classification yard lighting.

A classification yard, Figs. 3 and 9b, is used for the purpose of collecting freight cars into trains for particular routes and destinations. After a collection freight train has covered its allotted division taking all cars which have been loaded for shipment, it enters a receiving yard, Figs. 1 and 9a, where each car is inspected for defective running gear and where it is held until opportunity is afforded for it to pass over the scale, at which point each car is weighed and recorded as explained before. The switching, done below the scale clearance grade, is controlled from a tower

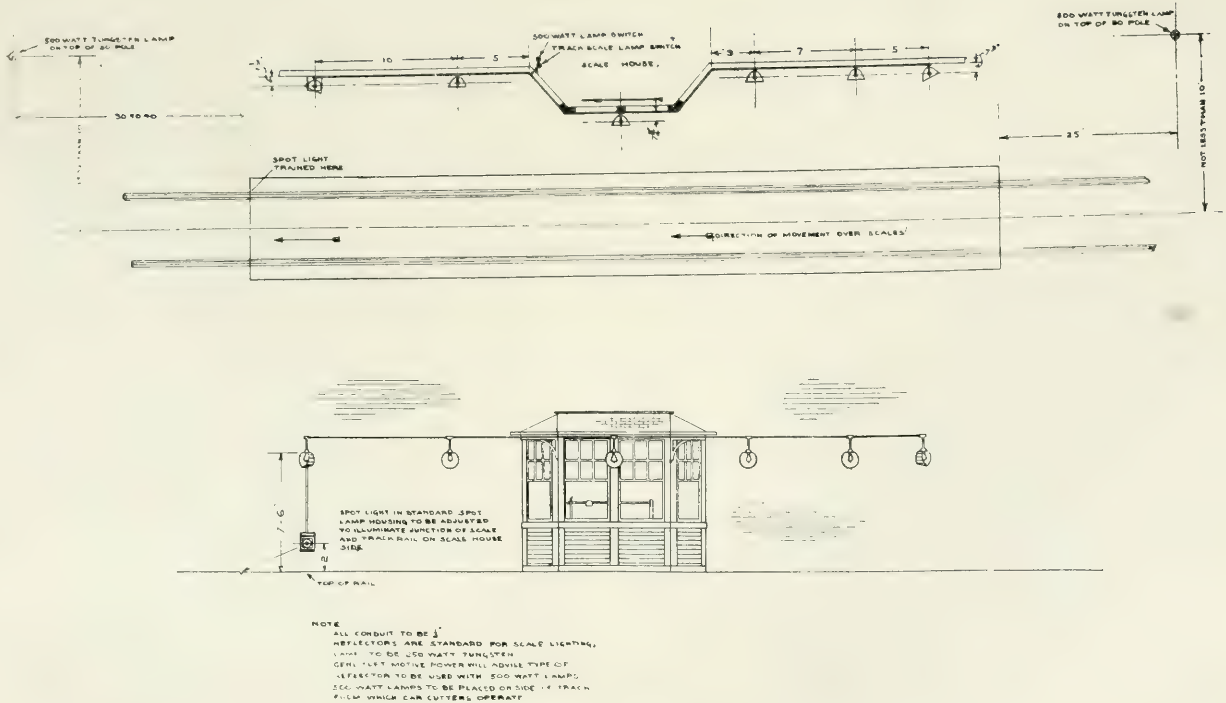

Fig. 11 —Scale house.

Fig. 12.—Yard lighting.

Fig. 13.—Yard lighting.

usually situated near the scale house Various layouts of tracks, pick-up tracks, etc., are in use, but a discussion of these is not necessary in this article. The trackage layout, however, should provide space for poles on which to mount lamps, and inasmuch as this layout is drawn up by the maintenance of way department, it is to be expected and is also true that the space allotted to the lighting is not only often insufficient, but also poorly located, as shown in Figs. 12 and 13. Also see Figs. 1 and 6. The usual lighting scheme employs a line of arcs down the center of the yard and a line on each side. Other methods have also been used, with as poor results, but being improvements over still poorer original methods they have been voted successes. A discussion of some of these methods will follow later in this article. For a moment, however, and in line with a previous thought expressed herein, the authors desire to present the probable consequence of a failure of light in a classification yard with the object of showing that the initial cost to obtain a correct layout will be but a small part of the loss produced by a failure, and that such an initial cost is justifiable, no matter how high it may be in comparison with the past practise.

As stated by the writers before, the major portion of a railroad's revenue depends on its freight haulage capacity. This capacity is as dependent upon scale and yard capacity as it is upon motive power equipment, and a congestion in either the receiving or classification yards or a reduction in car movement over scales will reduce earning power as well as will a disablement of locomotives or a lack of cars. Naturally, loss of revenue from any of these causes carries with it a cumulative losing effect due to loss of prestige and good-will of the shipping public. Bearing in mind the fact that work of the nature explained herein continues both day and night, it must be evident that a disablement of a classification yard imposes a mometary loss of no small magnitude to a railroad.

Every car or draft of cars going down the yard is manned by a rider, who conducts his charge to the cars already on the track. Inability to see ahead would result in accidents to men, cars and shipments, and would preclude all possibility of classifying

freight in a safe and economical manner. The lighting system employed is, therefore, an auxiliary of vital importance.

Many engineers in designing this class of lighting have considered a classification yard as an open space and have lighted it accordingly. An error of this sort will show, upon reflection, an incomplete consideration of the conditions to be met. Quite contrary to this idea, the problem of classification yard lighting may be stated to be more involved than any problem of street or park lighting. A classification yard consists of a series of streets 3 to 4 ft. wide, with buildings about 14 ft. high on both sides. The ideal system would, therefore, provide light on and between every pair of tracks. How close the ideal may be approached depends upon the allotted appropriation and the desires of the corporation and the designing engineer.

The conditions to be satisfied may be briefly stated as follows:

1. Illumination of the grade leading from the scale to the yard.

2. Illumination of the switches at the head of the yard to facilitate control of car movement from the switch tower.

3. Illumination of every track, irrespective of position of adjacent car.

4. Illumination of every car in the yard.

5. Absence of glare from every position in the yard.

The foregoing requirements must be accomplished without the retention of too much space from trackage, this space usually being allotted in advance, without regard to its adaptability for the purpose intended. The further consideration of type of illuminant and system to be employed will, therefore, be more or less dependent on other factors.

Many different methods have been employed, among which may be mentioned the following, with some of their advantages and disadvantages as viewed from an up-to-date standpoint, and in the light of the latest developments in lighting units.

SERIES A. C. ENCLOSED CARBON ARC LAMPS.

Advantages.

Simplicity.
- Generation of current.
- Distribution of current.

Easy control.
- All advantages of enclosed over open arc.
- Cheapness.

Disadvantages.

Poor power factor.
Low efficiency.
Poor distribution of light.
Necessity for reflector.

SERIES D. C. ENCLOSED CARBON ARC LAMPS.

Advantages.

Same as series a. c. enclosed carbon arc with better distribution of light.

Disadvantages.

Low efficiency and high maintenance cost when compared to latest series arc systems.
Necessity for converting apparatus in an a. c. plant or for a Brush arc machine.

FLAMING ARC LAMPS.

Advantages.

Series or multiple.
Long trim.
High efficiency.
Low maintenance cost based on flux of light produced.
Good distribution.

Disadvantages.

Tendency to flicker.
Necessity for extraordinary attention.

ARC PROJECTOR LAMPS.

Advantages.

Simple control.

Disadvantages.

Light all thrown in one direction, thus producing objectionable glare.

Limited area illuminated at any one time.

Traveling of car in its own shadow.

Blinding effect on return trip of rider resulting in danger.

Lower efficiency of lamp compared to luminous and flaming arc lamps.

Illumination of yard dependent upon a single source of light.

Total interception of light by string of cars on tracks adjacent to running track.

Necessity for constant attendance.

Necessity for special electrical apparatus to secure direct current, low voltage supply if transmission line is alternating current.

Interference, due to glare, in adjoining yards or on main line tracks adjoining.

Necessity for additional auxiliary lamps throughout the yard.

Inability to distinguish signals in the glare, especially green signals.

Excessive cost of maintenance.

Short life of trim—three and one-half hours.

LUMINOUS ARC LAMPS.

Advantages.

All advantages of series systems in general.

Good distribution of light.

High efficiency.

Long trim.

Reliability.

Low maintenance cost based on flux of light produced.

Disadvantages.

Necessity for converting apparatus in an a. c. plant or for a Brush arc machine.

SERIES TUNGSTEN LAMPS.

Advantages.

All advantages of series systems.

Almost ideal distribution, if installed correctly and small units used.

Either direct or alternating current.

Good efficiency.

Disadvantages.

High initial cost of installation, if small units are used (posts or catenary construction).

Necessity for reflectors to obtain desired distribution and overcome glare due to the low height of lamps, if small units are used.

QUARTZ LAMP.

Advantages.

High efficiency.

Good distribution for high mounting.

Good color value for outdoor illumination.

Large flux of light, which due to light distribution of the unit can be used to good advantage by high mounting of the lamp and large spacing.

Steadiness.

Disadvantages.

Requires direct current.

Is multiple unit only, necessitating large copper and large C_2R losses.

Large variation in candle-power with variation in temperature controlled only by readjusting resistances.

Present lack of data on reliability of operation and life of burners.

In Europe flaming arcs are at present being used to a great extent for railroad yard lighting. Labor and material costs here, however, have held up similar action in this country for the present. The question of how large or how small a unit to use depends on how close an approach to the ideal of bright moon-

light is desired. Other questions of maintenance are secondary, especially when the results of a failure are considered. The best that can be hoped for at present is the awakening and realization of the railroads to the value of good yard lighting. The best method will then be determined by intelligent effort and trial, if not by natural process of improvement and elimination.

The authors desire in conclusion to express their appreciation for the courtesies shown by the Pennsylvaina Railroad in furnishing valuable data used in the preparation of this paper.

DISCUSSION

MR. J. L. MINICK: I wish to add a word to what the authors have said regarding the troubles of railroad yard lighting. The classification yard with weigh scales is the point at which a very large portion of the total income is determined and it is therefore necessary to provide a reliable and efficient system of lighting to determine correct weights and to permit the rapid handling of equipment without injury to employees or the load.

The problem of properly illuminating the space immediately in front of the scale house was first solved by the use of flame arc lamps. The earliest lamps used had a trim life of from seven to ten hours. It was therefore necessary to trim the lamps twice each night in bad weather. Experiment showed that the re-adjustment of certain lamp parts would give a trim life of from twenty-six to twenty-eight hour—two full nights—in a lamp advertised to give seventeen hours but which in practise gave about ten. While this lamp served its purpose for several years, there was considerable difficulty and interruption of the service on account of flickering, slagging, and welding of the electrodes. Maintenance was unusually high in cost as it was frequently necessary to send an electric repairman on an entire day trip to some outlying point to correct some minor troubles. The development of the larger sizes of tungsten filament lamps has made available an illuminant that can be successfully substituted for the flame arc lamp.

The average height of a freight car is about 15 feet (4.57 m.). The average length of pole used in yard lighting runs from 30 to 35 feet (9.14m. to 10.66m.). If the lamp is placed on top of

the pole the distance from top of the car to height of lamp is from 15 to 18 feet (4.57 m. to 5.48 m.). Many yards are 300 feet (91.44 m.) or more in width and in most cases track space is so valuable that lamps cannot be placed within the yard. Essentially the problem becomes that of lighting a city of narrow streets and alleys, and tall buildings from lamps on poles of comparatively short length located in the suburbs. It is obvious that the successful lamp, unless placed on very high poles, must give maximum candle-powers slightly below the horizontal. The lamp approaching most closely to this ideal to-day is the magnetite arc lamp. Unfortunately it can be operated only on direct current circuits so that in many instances it becomes necessary to discard alternating current equipment and install rectifying apparatus to secure direct current.

MR. A. C. COTTON: In one of the yards shown in the pictures the tracks are not so laid out as to permit placing lamps in the middle of the yard. The lamps are placed at the side and consequently half of the expense involved is for lighting the surrounding country.

In order to get lights at switches, it has been necessary to suspend wires. There is no room for poles in such cases. On account of the box for switching apparatus, poles have had to be set off to one side, thus giving enough clearance on one side and not sufficient on the other. It is very unfortunate that illuminating engineers are called upon to endeavor to provide light where the clearances are so small.

In one of the other yards shown that fact was taken into consideration. There are two rows of lights through the yard, also one on the right and one on the left side. This yard was the last one built on the Western Pennsylvania division. In planning it the engineers had in mind some of the errors in other yards, and space was left to put in the poles. The ideal lighting arrangement would provide lights between each row of cars.

It is pretty hard when one goes to lay out an installation of lighting at such points as have been mentioned to interview all those who are interested. What is satisfactory to one man is not entirely satisfactory to another. It seems then to be a case of endeavoring to hit a happy medium.

The scale master of the Pennsylvania Railroad went into the lighting question quite extensively with the engineering department at Altoona. Those schemes you have heard explained this evening were sort of a compromise between the lighting units available at the time the first scales were placed and the conditions which were to be met. Of course as time goes on and other units of illumination become available, it may be necessary and advisable to change the present installations to something more efficient and desirable.

Flaming arc lamps of different makes, have been tried at different locations and under different service conditions and where different men were but have not been altogether satisfactory; hence the changing to the tungsten lamp. The cost of the installation is less with the tungsten lamp than with the flaming arc lamp. Most anybody can replace a tungsten lamp when it burns out.

The problem of this paper is known to the illuminating engineers who are working it out to the best of their ability with the co-operation of those who have to use the lights. Unless all the needs and desires of those who use the lights are known, the problem becomes a pretty hard one to solve.

Mr. J. L. Minick: The Northumberland yard of the Pennsylvania Railroad is lighted with magnetite arc lamps and this is probably one of the largest installations in the country. When it was first lighted it was found that one lamp had to be reversed and with that exception no trouble has been experienced. Most of the lamps used in the vicinity of West Philadelphia are flame arc lamps; and the yards of the Hudson Terminal Company near Manhattan Transfer are lighted by incandescent lamps. The Altoona and Harrisburg yards are lighted with alternating current arc lamps.

I am not sure that I recall correctly the distribution curve for the long life flame arc lamp. A 125-hour flame arc lamp is installed in West Philadelphia yard; it throws a large portion of its light near the pole with comparatively dark spots between lamps. I believe, however, that in the past six or eight months, a very earnest effort has been made to so improve the flame arc lamp that it will give the distribution of the magnetite arc. When

this has been accomplished this lamp can be used successfully in yard lighting.

Mr. G. W. Roosa: Flame carbon arc lamps have passed the experimental stage; but the manufacture of flame carbons has not reached a corresponding stage of perfection. The flame carbon arc lamp, therefore, is not to be condemned because of minor troubles which have not as yet been overcome in the flame carbon. It is gratifying to note, however, that a representative of one of the largest carbon manufacturers recently referred to the improvement in flame carbons during the last twelve months with considerable encouragement, especially with reference to the elimination of slagging and flickering.

About six months ago I made a series of tests to compare the unsteadiness of the intensity of light from the alternating current enclosed carbon arc lamp with that from an alternating current flame carbon arc lamp. Both types of lamps were tested on the same series circuit. I found by taking readings at a point about 45° below the horizontal that the variation in illumination intensity on the photometer screen was from 20 per cent. above to 20 per cent. below average intensity in the case of flame carbon lamp. The variation of the enclosed carbon lamp was from 24 per cent. above to 24 per cent. below the average. This seems to show that the flame carbon arc lamp and flame carbons have already reached a stage of perfection in regard to steadiness which is better than that of the enclosed carbon arc lamp and carbons.

Mr. C. R. Riker: I believe that greater emphasis should be placed on the effect of improved illumination on the efficiency of car movements throughout the yards. Of course, I know nothing about railroad yard lighting; but it is often found in industrial work that if an improved lighting system will enable a workman to save three or four minutes or more in the course of a day, almost any reasonable increased cost of lighting will be paid for by the increased production. Similarly, a certain number of extra cars passing the scales in a night will more than pay for the increased cost of an improved system of lighting, and I should imagine that the number of extra cars to make the improvements worth while, would be very small. It would

seem that this is one of the things which should be strongly emphasized in considering any improvements in yard lighting.

Mr. H. Kirschberg: A great deal of attention was drawn in the paper to the question of shadows, especially shadows of cars, and the possibility of mistaking a car for a shadow resulting in bumping of the cars and possibly dropping of the load. The question of using a large number of smaller units has been mentioned also as a closer approach to ideal lighting. But the problem from an economical viewpoint is, how far one should go in the use of space in a yard before more space is used than the lighting would justify and still at the same time maintain the yard at its highest efficiency.

The question of a good reflector for tungsten lamps for yard illumination is important. Now for yard lighting, the glare should be reduced as much as possible; it is therefore necessary to cover the lamp as much as possible. And on account of the dust, grime, etc., which are found in railroad yards, it becomes necessary to furnish an easily cleaned reflecting surface. In order to hide the lamp, the reflector must be opaque. The maximum intensity of the lamp, and a large portion of its light flux is slightly below the horizontal, so it should be possible to place a surface to intercept that flux of light and reflect it in the opposite direction as much below the horizontal as desired. A curved surface is therefore required, but in order to make this reflector up cheaply straight lines may be resorted to and will afford a satisfactory approximation. A similar reflector to the one described is used on the arc lamps over the stairs leading to the train platform of the Harrisburg station of the Pennsylvania Railroad. There was a condition there that illustrates this problem of glare very strongly. As one walks off the bridge, directly in the field of view is an arc lamp; in addition the stairs are constructed with a small rise and large tread and are not at all easy to walk on. Reports came from Harrisburg station that on an average of two people per week fell down those stairs. Investigation revealed that light might be the cause as the arc lamp so blinded people that they could hardly see where they were walking. As an experiment an opaque reflector was installed to cover the lamp entirely and at the same time give a

wide distribution of light. Thereafter, the number of such accidents decrease to two people a month, and these were usually women, the accidents having been caused mainly by long skirts and high heels. These reflectors could be used to very good advantage for classification yards.

MR. TRAVIS: In one yard I know of 250-watt tungsten lamps have been substituted for some of the flaming arcs. The opinion of the scale office men is that the service given is better and the 250-watt lamp is more satisfactory than that of the flaming arc.

MR. FLECK: As to the results obtained from tungsten lamps in place of flaming arc lamps, I will say that scale men state that they see very little difference and get just as good results.

MR. MEEKER: Three new modern scales have been on the Conemaugh division of the Pennsylvania Railroad and the question of lighting scales was duly encountered. The 250-watt tungsten unit seems to be giving satisfaction at all points. Arc lamps were not used on account of the flickering.

THE SPECTRUM.*

BY JAMES BARNES.

It is a well known fact that when the light from a glowing solid—for example the incandescent metallic filament of a lamp —is passed through a spectroscope of the greatest resolving power a continuous spectrum is obtained. There are a few exceptions to this statement. If, however, the light from a metallic arc or spark such as the mercury-vapor or the carbon dioxide tube lamp is analysed by a spectroscope the spectrum is found to be discontinuous; that is, it consists of fairly sharp lines. These lines in may cases are not distributed in a haphazard manner but their wave-lengths and therefore the frequencies of the vibrations which give rise to them, are connected by simple equations. Balmer followed by Kayser, Runge and Rydberg have done an immense amount of work in this field. Probably the most remarkable and satisfactory formula proposed so far is one of the Rydberg type. As stated by the late Dr. Ritz it is as follows:

$$n = A - \frac{N_0}{\left(m + a + \frac{b}{m^2}\right)^2},$$

Where n is the frequency, A the convergence frequency of the series, N_0 a universal constant, *i. e.,* it has the same value for all series, and $m = 2, 3, 4,$ etc. The problem now before us is—what does this expression mean? Does it give a clue to the structure of the atom?

In this connection allow me to draw attention to the famous Zeeman-effect so called. Zeeman and his followers have shown that practically all of the lines of a line spectrum are split into components when the source is placed in a strong magnetic field. In contrast with this, the lines of a banded spectrum are not influenced by a magnetic field, although some recent work by Dufour has shown that the band spectra of calcium, barium, and

* An abstract of a paper read before a meeting of the Philadelphia section of the Illuminating Engineering Society.

strontium fluorides and chlorides are slightly affected. It was Lorentz who showed that the Zeeman-effect could be explained by assuming that the energy producing these lines was radiated from negative electrons, for the calculation of the ratio of the charge to the mass from the shifts of the components of the lines gave values comparable with those obtained for the negative electron involved in the discharge in an X-ray bulb and for the B-rays from radioactive substances. The state of the polarization in these components showed also that the sign of the charge was negative.

Thus if it is assumed that the atom consists of a system of revolving electrons one has the equivalent of a number of small elementary magnets. The periodicity of the motions of these magnets will certainly depend on the strength of the external magnetic field. This idea is due to Ritz, but has not been considered by physicists as altogether satisfactory, for as Prof. J. J. Thompson says "from physical considerations the proposed system is too improbable to make one feel much satisfaction with it.

To return to the case of the spectrum of a solid: one may remember the curve showing the relation between the energy radiated and the wave-length. The formula which fits it best is one due to Plank. This black-body radiation equation assumes that the emission of energy in this form takes place discontinuously with time—that the oscillator whether an electron, atom or molecule emits a certain *quantum* hv or some integral multiple of this unit. In this expression h is a universal constant and v the natural frequency of the oscillator. The fact that Plank's equation deduced on this assumption agrees so closely with the experimental observations is certainly a point in its favor. Not only this, but the theory is very suggestive and of much importance to the technical man so that one may close with the remark so often made that a theory should not only generalize the known results, but also point out the way for fruitful investigation. Measured by this standard this new and rather revolutionary assumption of Plank has much to its credit.

DISCUSSION.

Mr. M. Luckiesh (Communicated): Prof. Barnes has given us a peep into the wonderland of the spectrum. There is no more interesting branch of physical science than that pertaining to the spectrum and research is focussed upon this field from various directions by many scientists. The spectrum forms the basis of spectroscopic analysis. It is a connecting link between physical and chemical science and from its study science hopes to lay bare the secrets concerning the constitution of the atom and perhaps of matter.

To the illuminating engineer the spectrum is of extreme interest and importance. The scientist is primarily concerned with the spectrum in his efforts toward artificial light production. The spectral character of the radiation determines the efficiency of the light source. A knowledge of the characteristic spectra of the elements resulted in the production of the Welsbach mantle, the flaming arc, the vacuum tube lamps and other sources and plays an important part in all efforts toward the production of light.

The illuminating engineer is especially interested in the spectra of the available artificial sources after science has presented them to him. Upon the spectral character of the visible radiation very largely depends the success of the light source. Visual acuity, the appearance of colored objects, the penetrating power of light, possible injury to the eyes and the actinic value are all dependent upon the spectra of illuminants as well as perhaps eye fatigue and various effects more or less psychological in nature.

Spectral character, or quality of light, is perhaps the most important factor in the science and art of illumination, the remainder of illuminating engineering procedure being summed up in distribution. Not only are the spectra of illuminants of interest to the lighting specialist, but also the spectral character of the light reflected from wall coverings and other objects and of the light transmitted through and reflected from lighting accessories. From the standpoint of illuminating practise the quality of light is highly important and as the science and art of illumination is developing, more attention is being given to this factor.

A SIMPLE UNIT METHOD FOR MEASURING THE ACTINIC EFFECT OF ILLUMINANTS, BOTH PRIMARY AND SECONDARY, IN THE PRACTISE OF PHOTOGRAPHY.

BY FRANK MORRIS STEADMAN

Synopsis: The treatise of which the present paper is a brief abstract was written in the hope of establishing a rational scientific foundation for the practise of photography and for the study of light as it is daily observed in nature. It was shown that the chemical energy of light, the relative aperture of a lens, the degree of sensitiveness of photographic emulsions, which are the fundamental elements in photography, are at present lacking simple units of measurement. The whole system has been named by Mr. Steadman "Aabacraft Photography." A term "actinism" is used and defined to denote the chemical property of radiation and a unit of it under specified conditions is called an "actino." A practical actinometer is described and its use explained. A unit cone system for the measurement of light convergence is developed and the relation of such a system to the systems of lens stops, now in use, is explained; also the Hurter and Driffield work in their analysis of what may be called a "perfect printing negative" is developed. The theory of the "characteristic curve" of a given photographic plate and the "law of constant density ratios" are gone into with considerable detail. The paper includes also a number of problems illustrating the important points considered.

It is safe to say, I think, that there is no sort of work involving the use of physical quantities which is practised in a way so chaotic and without method as is photography. For example lens and camera makers are at liberty to place any arbitrary scale of numbers they wish on a series of lens stops, and as there is no accepted or standard unit scale for this purpose, the United States Bureau of Standards or that of any other country has no interest or authority in the matter.

Thousands of cameras are turned out each year without any lens-diaphragm scale whatever and for the lack of a comprehensive *unit* scale comparatively few persons using a camera know the meaning of the scales which ordinarily are used. In the Uniform System (U. S.) for example, which is used in our own country on a large number of the cheaper and most popular cameras, the various openings are designated by numbers which were intended to represent the relative times of exposure with the different openings. The result of this is of course that the

larger openings have the smaller numbers. This was an attempt to work out beforehand the problem of exposure, or a part of it, but the effect has been that a novice who buys a camera so numbered is at once confused.

Almost by instinct even a child feels that the number "one" should represent some tangible and comprehensive individual thing so that "two" may mean two of them or something twice as large. It is this instinct that demands a simple unit scale for designating lens stops as is the case in other measurements in our daily experience.

More attention is being paid in these days than formerly to the matter of the intrinsic brightness of surfaces. This is practical since, given a source of light, in an office for example, the distance of a desk from this source is what almost wholly decides its illumination.

In photography it is still more necessary to consider the brightness of lighted objects since it is rare indeed that a primary light source is photographed. Since, further, we are dealing in photography with a special quality of the light emitted from surfaces, *i. e.,* its ability to affect the emulsions on the plates or films, it seems appropriate to coin the word *"actinicity"* to represent in a quantitative way this property, *i. e.,* the *photographic* value of the light from any object. For this purpose it is proposed to derive a simple unit of actinic measurement based upon the power of the light to tint some convenient photographic medium such as the emulsion on the ordinary film or the slower medium on any printing out paper such as solio.

A vast majority of photography is done with the subjects in direct sunlight, though the sky as well as the sun plays a very important part in the illumination of the objects photographed. On the other hand portraiture and much other work should be done under a completely diffused light source, the light being compositely reflected from the sky in conjunction with all objects in view.

In considering such an extended expanse of light source as shining upon a certain small surface and creating there a measurable intrinsic actinicity, there is presented to the mind a form of illumination which corresponds to that of a cone whose base

is the expansive light source and whose apex is any point of the illuminated surface. On placing such a lighted surface out of doors and high up in horizontal position where the sky-line would not be broken, it is clear that upon each point of that surface light will converge from the whole hemisphere of sky. Any part of the surface may be covered with an opaque screen in close contact with it and the remainder will of course have the same illumination as before. Now if this lighted surface were stood up in a vertical position, only half of the sky could send light to it, but on the other hand half of the earth surface or that hemisphere of space from the horizon downwards could also illuminate it, although of course less intensely than the sky.

It is clear then that each individual point of a surface is impinged upon by light from the whole hemisphere of space which confronts it.

By limiting the convergence of light from any surface to a known cone form, it is evident that its intrinsic actinicity may be determined by measuring the time required for the light from it to produce a specified effect on a body which is visibly changed by that light. It is found also that such an idea is in exact conformity with the theory which is recognized as true in denoting the value of lens apertures by the focal or "*f*" method. For example stops whose diameters are equal to 1/8th of the focal length of the lens are considered as having the same working speed regardless of the actual focal length. Thus in a lens having a focal length of 16 cm. the diameter of the f-8 stop is 2 cm.; in a lens of 24 cm. focal length 3 cm. etc. I shall return to this question presently.

From the discussion immediately to follow it will be seen that by subdividing the sphere to find a practical cone unit for this method it has been easy to secure a unit that is practical for expressing the values of lens stops, the unit chosen being the form of f-64, or a cone whose altitude is 64 times the diameter of its base, and which is a trifle smaller than the smallest stop usually designated on the diaphragms of lenses and shutters. Number 2 of the series has a working speed of 2 units and the scale therefore fulfills the requirements which the mind so logically demands of it.

Plane and Solid Angles.—If two mutually perpendicular lines be drawn through the centre of a circle, four right angles are formed, each subtended by *one quarter* of the circumference. Again, each of these quadrants may be halved or further subdivided at will. If now three planes mutually perpendicular be passed through the centre of a sphere, eight equal solid angles are formed called octants, each subtended by one eighth of the spherical surface. If further a circle be drawn on the surface of the sphere equal in area to one of the octants, this circle may be said to subtend a solid angle at the centre equal to one eighth of the sphere, and the solid geometrical figure thus defined will evidently be a circular cone with its apex at the centre and having a spherical curved base. From this it is seen at once that, if straight lines be drawn from any point in space to every point of the outline of some subject as a door or window, the latter will subtend at the point a definite measurable part of the total solid angle subtended by a spherical surface drawn about that point. Evidently as the point approaches the object the solid angle subtended will increase.

If the apex of the cone of light subtended by the door or window in the foregoing illustration be located upon some light sensitive surface, as that of a silver emulsion, then the greater the convergence of light from that source, the less time will be required to produce a stated chemical change. Now every object about us, even one so indefinite as the sky, emits light capable of effecting this chemical change to some degree; this property then is evidently a quantitative one and as will be shown can be measured in simple units. This property has already been termed actinicity.

In taking up the discussion of the unit of actinicity it must be understood that the purpose of this system is not to suggest a primary light source of unit power as a standard but to furnish a practical means of measuring the intrinsic actinicity of all light sources, as the sun, the sky, flames and all sources about us in nature.

The f System.—It can easily be demonstrated that if a circle be drawn on the surface of any sphere equal in area to one half of one of its octants above referred to, the diameter of this circle

will equal approximately the radius of the sphere and therefore the altitude of the corresponding cone. Now as has been seen, the usual method of denoting the light admitting property of a photographic lens, is to express the ratio of the diaphragm diameter to the focal length of the lens; hence the focal or *f* system.

Thus in the accompanying diagram, Fig. 1, if *ab cd* represent a bundle of parallel light rays incident upon a lens, the light will be concentrated at the point *o* called the focus and situated at the distance *eo* from the lens known as its focal length. The focal length for a lens of any given diameter is evidently dependent upon the curvature, the refractive index of the glass, etc., but the amount of light per unit area of the spot at *o* is directly proportional to the area of the lens opening or to the square of *bd,* and inversely proportional to the square of the distance *eo.*

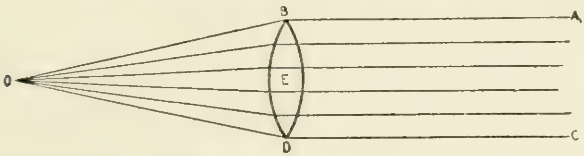

Fig. 1.—Light convergence.

The intensity of the effect at *o* therefore is proportional to the square of the ratio of *bd* to *eo.* This ratio *bd/eo* is called the *relative aperture* of the lens and is the basis of the *f* system for indicating lens speeds. For example as in the cases above cited if a lens of 16 cm. focal length is used with a diaphragm opening 2 cm. in diameter, the former is eight times the latter and the relative aperture is expressed f-8. If the full opening of this lens be 4 cm. in diameter the focal length is only four times this diameter and the relative aperture will therefore be f-4. As the base of the cone of light admitted with the f-4 opening is four times as great as with the f-8 opening, the altitude being the same, the illumination at *o* will be four times as intense with the former as with the latter and the necessary exposure for taking a picture one fourth as great.

Derivation of the Unit Cone.—Referring now to the spherical cone in which the diameter of the base equals the altitude, it follows that it might be described as being equivalent to a rela-

tive aperture of f-1, and as every point of the surface about us in nature is a point of convergence of cones of light emitted from all the objects which confront it, it becomes necessary to evaluate these cones as a means of determining one of the elements of actinicity. A unit of measurement must then be sought and defined.

Since it is the custom to graduate lens diaphragm scales so that each number in the series indicates a speed half that of the next lower, the idea was suggested that by successively halving a spherical surface a small cone might be attained approximating in value one of the smallest practical values in the *f* system. This is evidently the case since an f-1 cone has been seen to be approximately 1/16 of a sphere. Now since f-64 is the smallest practical relative aperture used in photography, it is at once suggested to adopt the corresponding cone as the unit cone. Since f-1 equals 1/16 of a sphere, and the cone values diminish as the squares of the *f* values, f-64 will equal $\left(\frac{1}{16} \times \frac{1}{64^2}\right) = \frac{1}{65{,}536}$ of a sphere. As mathematical accuracy is not demanded this fraction may conveniently be expressed as $\frac{1}{64{,}000}$ and may be written $\frac{1}{64M}$, and by the adoption of this particular number the geometrical progression with ratio 2 is preserved which much facilitates mental calculations.

The table which follows expresses the sphere value, the *f* number, the Uniform System number and the cone unit value of all cones from f-64 to f-1:

Sphere value (approximately)	*f* number	U. S. number	Cone unit value
1/64M	f-64	256	1
1/32M	f-45+	128	2
1/16M	f-32	64	4
1/8M	f-22+	32	8
1/4M	f-16	16	16
1/2M	f-11	8	32
1/1M	f- 8	4	64
1/512	f- 5.6+	2	128
1/256	f- 4	1	256
1/128	f- 2.8+	1/2	512
1/64	f- 2	1/4	1024 or 1M
1/32	f- 1.4+	1/8	2056 or 2M
1/16	f- 1	1/16	4096 or 4M

The *least visible tint* on some chosen tinting medium is the effect adopted as a standard. The absolute actinic unit logically must be defined then as the rate of emission of actinic radiation from a surface just actinic enough to produce the least visible tint on the chosen standard medium in *one second* when the convergence is *one cone unit*. As in the case of many other absolute physical units this is impracticable in ordinary use since measured in this manner the surface of the sun itself when high in the heavens and the atmosphere clear, would have an intrinsic actinicity of only 128 units and all ordinary intensities would have to be expressed in fractions. A surface as bright as the brightest sky would have only about 1/512 of this unit actinicity. It is evident therefore that a much lower actinicity must be chosen as the practical unit.

The unit actually chosen is that rate of emission which will produce a least visible tint in one minute (64 seconds) when the convergence is f-1 (4096 cone units). This practical unit of actinicity is called an *actino*. For the present it is evident that a desirable and all round acceptable standard tinting medium is difficult to find. It has been found however that although dry plates and films vary greatly in their *latent* speed they are practically all alike as to the speed with which they tint visibly when exposed to light. For practical purposes then it is recommended that the measurements be made on ensign or kodak film or any other film which does not contain an orthochromatic dye, as the presence of such a dye retards the tinting speed.

The practical reason for adopting these specifications for the value of an actino is that ordinary surfaces about us, as for example a face when lighted for portraiture will present from 4 to 64 actinos, the sky when the sun is high about 512, and the sun itself about 32,000,000 actinos.

It is seen therefore that the value of the practical unit of actinicity is chosen purely for convenience in practise just as the practical units in other departments of physics have been chosen.

The Latitude of Emulsions.—The latitude of an emulsion is its capacity to render in perfect gradation different degrees of actinicity in the same subject. An emulsion is said to have

great latitude when it will register greatly differing intensities and to be "hard" or contrasty when it will register comparatively little actinic contrast or when a little actinic contrast in a subject suffices to fill, or fully utilize, its graduation capacity.

The latitude of an emulsion is indicated by the relative length of the straight part of the "characteristic curve" of the emulsion to be described presently. It may be found by ascertaining by trial the fractional part of its correct speed-time exposure which will suffice to create a just clearly visible deposit in the emulsion after normal development. Such an exposure is known as a *one inertia* exposure, since by normal development it only suffices to overcome once, so to speak, the inertia of the emulsion. The number of times the normal or speed-time exposure is greater than the one inertia exposure, may be used as a factor to express the latitude of any emulsion. For example should the normal speed-time of a certain plate be 2 minutes or 128 seconds and an exposure of 8 seconds, under the equivalent of unit conditions, suffice to show a faint deposit after normal development (one of 4 seconds revealing no deposit) then 8 seconds may be known as the *one inertia exposure* for that emulsion and the latitude of the emulsion would be 16 since 128 seconds divided by 8 equals 16. Expressed in other words, that emulsion is found to endure normally a 16 *inertia exposure* since the normal or speed-time is 16 times the one inertia exposure.

Exposure may be comprehended as the act of overcoming the inertia of an emulsion a greater or less number of times, an over exposure doing so too many times and an under exposure too few; while a normal exposure overcomes the inertia the correct number of times, thus producing the desired effect in the negative with normal development. On developing snap shots made by the novice in the shade or any too dull light it frequently happens that the brightest parts of the subjects have impressed themselves on the emulsion only just enough to develop to a visible deposit. In such cases those planes have received but a one inertia exposure and as an average emulsion was used, *i. e.*, that of roll film of which none are made of a "hard" quality, it would have required from 16 to 32 times the exposure actually

given to have prepared the latent image for development into a normal negative.

The latitude 16 may be considered as the average and is that of the usual modern fast plate. Films on the whole have greater endurance probably by reason of the entire absence of glass in their construction, which makes them naturally of a "non halation" quality. The latitude 8 is "hard" or contrasty and of 4, if this hardness is reached, is extremely contrasty.

The average and soft emulsions are to be used for the average view and for portraiture and all subjects having ordinary contrasts. The hard emulsions are used more especially for photomechanical or process work in which it is required to get extreme contrasts from flat prints or to obtain effects in black and white as in the production of white lines on a dark ground or the reverse. However when the illogical desire for speed has run its course among photographic workers and emulsions are selected purely by reason of their quality or latitude, which is simply their adaptability for subjects of certain known contrasts, then these hard emulsions will be used much more for all those subjects which have but little contrast, such as bird's-eye views and copies in general.

On these hard emulsions a little more than the correct exposure seems, on development, quickly to clog the film and spoil the gradation steps completely, they having but little endurance. These emulsions seem usually to be quite thinly coated and to develop much more rapidly than emulsions of more latitude or softness and care should be taken therefore not to over develop them. The normal developer should be diluted by nearly an equal quantity of water or the time of development be reduced to nearly half. Since the latitude of these emulsions is so limited, it is evident that more than the usual care should be exercised in order to arrive at the correct exposure.

A number of years ago two Englishmen, Messrs. Hurter and Driffield, made a rather complete investigation of the photochemical properties of a photographic plate, the immediate object of which was to provide the amateur with a method of determining the speed of the plates used and to influence them to substitute methods of scientific precision for the wasteful and

disappointing guess-work methods generally practised. Their work which really began with the introduction of the gelatin dry plate, was continued for a number of years and finally published in a very concise and readable form.[1]

It is clear that the practise of photography must resolve itself into two parts—the purely artistic and the distinctly scientific. It is for the artist to show the picture—for the scientist to reproduce it. It is then to the method of truthfully representing natural objects with special attention to the various intensities of light and shade that we shall direct our attention.

A Perfect Negative.—The aforementioned authors defined a technically perfect negative as "one in which the opacities of its gradations are proportional to the light reflected by those parts of the original object which they represent;" and their research showed that such a relation may exist but only when a plate has received correct exposure, and also a proper time of development. The reason for this definition is clear when we remember that the negative is only a printing screen for use in making a positive picture and that the brightness of any spot on the print is directly proportional to the opacity of the corresponding area of the negative.

In the above definition the term "opacity" is assumed to be the reciprocal of "transparency," this being the fraction of the incident light that a layer transmits. Thus the transparency of a film of reduced silver which transmits one third of the light incident upon it is 1/3, and its opacity is 3. If the term density be applied to the actual quantity of silver deposited per unit area, it can be shown that density forms a convenient transition between opacity and the "exposure." In this discussion "exposure" will be understood to mean the product of the illumination expressed in proper units by the time during which the action lasts.

This is clear from the following discussion. Suppose one has four areas *a, b, c, d,* on some negative on which the silver deposit per sq. cm. occurs in the ratio of the numbers 0, 1, 2 and 3; these then may be taken as the several densities of the areas, and are in arithmetical progression. Suppose now that the

[1] *The Photo Miniature*, Nov., 1903 (Vol. V, No. 56).

thickness of the area *b* be such that 1/4 of the incident light is transmitted. As area *c* has twice as dense a silver deposit as *b*, the light transmitted through it will be just as if *c* were made up of two superposed layers each like *b*. In this case the light incident on the under layer being 1/4 that incident on the upper, the two layers together will transmit only 1/4 of 1/4 or 1/16 of the initial amount. So the areas transmit respectively *a*1/1, *b*1/4, *c*1/16 and *d*1/64 of the quantity of light incident on each. As these numbers represent the transparencies, their reciprocals will denote the opacities or *a* 1, *b* 4, *c* 16 and *d* 64.

Starting with the densities in arithmetical progression 0, 1, 2, 3, it has been found that the corresponding opacities are in geometrical progression 1, 4, 16, 64, from which the following relations are evident, *viz.*, $4^0=1$, $4^1=4$, $4^2=16$, $4^3=64$. This is the same as saying that the density is proportional to the logarithm of the capacity, since $0=\log_4 1$, $1=\log_4 4$, $2=\log_4 16$ and $3=\log_4 64$, the base of the system depending on the scale of contrast chosen in the areas.

Had area *b* been so thin as to transmit 1/2 the incident light, the base of the system would have been 2 instead of 4; but still the opacities would have been in geometrical progression, the corresponding densities being in arithmetical progression—a logarithmic relation.

It is clear then that the densities of a series of areas on a negative are always proportional to the logarithms of the corresponding opacities, but if the negative represent proper tone gradations, the additional conditions must hold, *viz.*, the opacity must be proportional to the exposure. Therefore for a technically perfect negative the density should be proportional to the logarithm of the exposure. Thus it is seen that the law of true tone graduations is expressed by saying that the quantity of reduced silver per unit of time at any point in a negative is proportional to the logarithm of the light intensity incident at this point. The conditions under which this is possible are discussed in the following paragraphs:

The Characteristic Curve.—The above proposition was experimentally demonstrated in the following way. Thickly coated slow plates were found best for experiment. Upon one of these

a series of exposures was made beginning with one second and doubling the time at each successive exposure. The times of exposure with a constant source of illumination were thus in geometrical progression. After development the density resulting from each exposure was determined and its value with the corresponding exposure plotted as shown in the curve, Fig. 2, the geometric series of exposures being laid off equidistant on the horizontal axis. This curve is to be known as the "characteristic curve" of the plate. On examination the curve is found to consist of four distinct parts, corresponding respectively to the exposures 1 to 32 seconds, 32 to 1,024 seconds, and two other

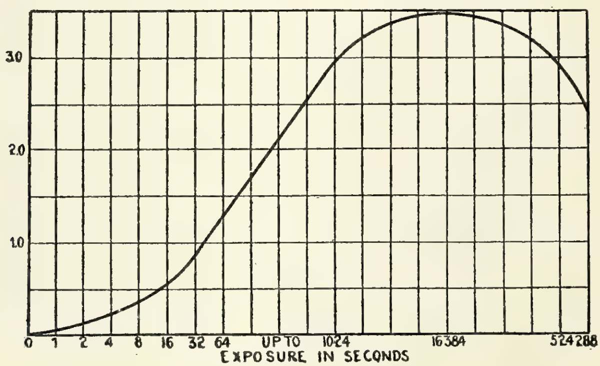

Fig. 2.—Characteristic curve.

parts corresponding to still greater exposures. It will be noted that the second part is a straight line which signifies that the vertical distances are proportional to the horizontal distances, but the vertical distances which represent the densities actually measured are in arithmetical series while the corresponding horizontal distances are made to represent numbers in geometrical series, these numbers denoting the exposures. Thus the densities are seen to be proportional to the logarithms of the exposures in this part of the curve, and therefore this part of the curve expresses the law of true tone gradations.

For exposures 1 to 32 seconds the density increases approximately with the exposure and would continue to do so for larger exposures but for the fact that the effect of the light can only

result on the *unaltered* silver present at any instant, and this of course is gradually decreasing so that a second of exposure to a given light agent at the end of a minute would add a far less increment to the density than it would at the end of 5 seconds when there would be so much more unaltered emulsion to act upon. As then at first the densities vary as the exposures, the opacities will increase much more rapidly and the effect of printing will be one characteristic of an under-exposed negative *i. e.*, a too great contrast of light and shade.

Similarly it can be shown that the third part of the curve corresponds to the period of over-exposure in a plate in which the growth of density in the brightest lighted parts is so slow compared to the exposure as to result in a plate of too little contrast. The more strongly lighted parts have become nearly saturated with altered silver and do not increase much in density with time, while the less lighted parts are still increasing rapidly with time. The result is obviously a flat negative.

The fourth branch of the curve corresponds to the period of excessive over-exposure resulting in a reversal of the image. This has been studied in detail by Nipher and others.

Referring again to the straight part of the characteristic curve it will be noticed that for the particular plate used, any exposure from 32 to 1,024 seconds would have produced a technically correct negative. This range or "latitude" is different for different plates, as has been explained, and is taken into account in selecting a plate for a particular purpose. Further, to produce a properly graded negative the exposure must be within the limits assigned by the latitude. By no special method of development is it possible to change the *density ratios* on any particular plate. The *actual* densities at the different points of a plate are of course dependent on the kind of developer and the time of development, but not the ratio of the densities at any two points.

Law of Constant Density Ratios.—An important part of the work of Hurter and Driffield was the experimental demonstration of the statement made in the last paragraph, *viz.*, that the ratio of the densities of any two areas of a finished negative is independent of development. A plate was exposed in three sections crosswise to a candle light placed a meter away, the first

section being exposed 1 1/4 seconds, the next 2 1/2 and the third 5 seconds. The plate was then cut into three strips lengthwise, each strip therefore having on it three different exposures. They were then developed in the same solution for 4, 8, and 12 minutes respectively, and the nine densities measured. From these the density ratios, the opacities, and the opacity ratios were calculated and all tabulated as shown below.

	1 Exposure	2 Density	3 Density ratio	4 Opacity	5 Opacity ratio
Strip No. 1......	1.25	0.310	1.0	2.04	1.0
Developed	2.5	0.520	1.67	3.31	1.62
4 minutes	5.0	0.725	2.33	5.30	2.59
Strip No. 2......	1.25	0.530	1.0	3.38	1.0
Developed	2.5	0.905	1.70	8.03	2.37
8 minutes	5.0	1.235	2.33	17.18	5.08
Strip No. 3......	1.25	0.695	1.0	4.95	1.0
Developed	2.5	1.140	1.64	13.80	2.78
12 minutes	5.0	1.625	2.33	42.17	8.51

The density ratios of the three exposures for all periods of development are seen to be practically the same. The densities, the opacities and the opacity ratios all increase with the time of development. Since the exposures are as 1 : 2 : 4, it will be seen at a glance that the opacity ratios coming nearest to this are those resulting from the 8-minute development. It may be estimated that had strip No. 2 been developed about 7 minutes the opacity ratios would have been about as 1 : 2 : 4, and this strip would then have been technically perfect as to its tone gradations, the several opacities being proportional to their exposures. Strip No. 1 is seen to be under-developd, while No. 3 much over-developed.

Having exposed a plate correctly then it is seen from the above results that it is equally important to develop it for the proper length of time. As has been made clear the straight part of every characteristic curve, whatever the time of development, indicates a direct proportionality between the density and the logarithm of the corresponding exposure. The *slope,* however, is seen to increase with time of development, and there is only one slope for which the various opacities are so graded that the corresponding densities are proportional to the logarithm of

them; *i. e.*, there is only one slope, or time of development, which in any particular case will result in a technically perfect negative according to the definition. The trigonometric tangent of this particular slope may be called the "development factor" for the plate. Theoretically this should be unity or the slope should be 45°. Practically it may vary somewhat from this in the effort to produce special effects deviating at will from a truthful representation of the subject.

Now to find the speed of any dry plate or film it is only necessary to photograph a surface of unit actinicity with the unit stop in the lens and by trial, employing a series of exposure times which increase by doubling, find the time required to get a perfectly exposed negative. By making a series of exposures so that at the lower end of the series there shall be one that just overcomes the inertia of an emulsion by normal development it can be seen the number of times this "one inertia" exposure is required to effect a correct or normal exposure on that emulsion in the highlight part of the image. The correct effect is easily observed since a too much exposure tends to dull or run together the texture rendering from such surfaces as the skin or an ordinary cloth. This method discloses also the contrast quality of emulsions, a contrasty one being fully effected in the high lights by an 8 or a 16 inertia exposure while a soft working one will endure nicely an exposure of 32 or 64 inertias.

The ordinary kodak film has a speed of about 8 minutes. That is, should a surface present itself in practise which has one unit af actinicity the speed of the film is such that the exposure would be 8 minutes with the one unit stop in the lens. But should a 16 unit stop be used it is evident that only 1/16 of this 8 minutes will be required, or 1/2 of one minute or, to keep in the geometric scale of numeration, 32 seconds. Also should the surface to be photographed measure, for example, 8 units of actinicity instead of one, this 32 seconds would be reduced to 4 seconds as the exposure.

The exposure rule by this method is therefore as follows: *Divide the speed time of any emulsion by the actinicity of the surface and again by the value of the stop employed in the lens. The quotient will be the full normal exposure for the plate or film employed.* If it is desired for any reason to overcome the

inertia of the emulsion a less number of times this exposure is reduced accordingly.

The f-1 meter for measuring the actinicity of surfaces or light sources can be any small arrangement as a small box in one side of which is a small "contact" opening through which the tinting medium may be tinted in close contact so that its outline may be looked for on the medium after exposure, as a help in detecting the tinted spot, and opposite this opening must be another having the diameter of the thickness of the box or of the distance from the plane of the f-1 opening to the "contact" opening. This arrangement should be painted a dull black on the inside or lined with black velvet to absorb as much as possible the rays which are incident within it.

Two conditions are necessary to observe in using the meter. One is that the surface must be of uniform or nearly uniform intensity throughout the patch being measured. Otherwise it is clear that a single intensity would not be measured but rather an average of different intensities. The second condition is that the meter be held close enough to the surface so that the latter entirely fills the f-1 opening, or the meter must be held a little closer to the surface than the least extension of the latter. Since 64 seconds is the unit tint time the rule for using the meter must be: Divide 64 by the least visible tint time of any surface to get its intensity in "actinos" or units of actinicity.

On exposing the film through the meter to the light from an illuminated white cloth it is found by several trials, that 16 seconds suffices to produce the least visible tint and 64 divided by this number gives the intensity of the surface as 4 actinos. Now according to the exposure rule already given, 8 minutes divided by this actinicity gives 2 minutes or 128 seconds, and this exposure with the unit stop would produce a perfect normal exposure on the film in hand. But should a 16 unit stop be employed this exposure would be reduced again to 1/16 of 128 seconds or 8 seconds. The correctness of this exposure will be best illustrated by giving also exposures 1/8, 1/4 and 1/2 normal so that the gradual increase of opacity to the normal point may be seen.

Four problems seem to present themselves naturally in this method and they will be noticed briefly.

Problem 1.—To find the actinicity of any surface of known average diameter and known distance from the tinting medium, *i. e.*, of known cone value.

To illustrate this, suppose that the average actinicity of the brightest part of an ordinary arc lamp is desired. Assuming that the bright spot is about 3 mm. in diameter, in order to measure it alone, it is necessary to exclude the surrounding light from striking the tinting medium. This is possible by exposing through a small aperture of say 2 mm. in diameter at a distance of 64 times this diameter from the aperture. This gives the unit cone conditions of f-64. If the tinting medium be solio which is 8 times slower than the standard film, the tint-time is found to be 1/2 a second which would be equivalent to 1/16 of a second with the standard film. Now from the inverse square law it is clear that had the light source illuminated the medium at a convergence of f-1 as demanded by the meter, the tint time would have been $\frac{1}{64^2}$ of 1/16 of a second or about $\frac{1}{64,000}\left(\frac{1}{64M}\right)$ of a second which may be called the f-1 meter time of that source. As already stated 64 divided by the meter time gives the actinicity of the source in actinos which in this case came to about 4,000,000 (4MM) actinos. Four minutes, or 256 seconds, the speed of this film divided by the actinicity gives $\frac{1}{16,000}$ of a second or the exposure required to photograph the source with unit stop, correspondingly shorter exposures being sufficient for larger apertures.

Problem 2.—To find the actinicity of a distant surface of small convergence and low value.

A candle flame may be chosen to illustrate this problem. By casting an image of the flame on the tinting medium by means of a lens at f-4, the tint time will be practically the same as though the medium were held 4 diameters of the flame from it. The time is found by trial to be 128 seconds which divided by 4^2 as before gives the tint time at 8 seconds with an f-1 meter. Then 64 divided by this meter time gives 8 actinos for the intensity of the flame. Therefore to photograph the flame on a film of 4 minutes speed would require with unit stop 1/8 of 4 minutes (or 32 sec-

onds) and with a 4 unit stop for example 1/4 of this or 8 seconds. Successive exposures of 4, 2 and 1 seconds should be given to show the approach to the proper exposure.

The full moon near the zenith measures by this method 64 actinos and with a plate having a speed of 4 minutes or 256 seconds the exposure with unit stop is 4 seconds $\left(\frac{256}{64}\right)$. With stop 4 the exposure is 1 second, and with stop 256 (f-4) $\frac{1}{64}$ of a second $\left(\frac{4}{256}\right)$. It is clear therefore that with a very rapid lens a practically instantaneous exposure may be given.

Problem 3.—To find the actinicity of any surface by taking the first appearance time at that surface or, in other words, of the light incident upon it.

On measuring the light emitted from any surface, as already explained, the standard f-1 meter is used and should 64 seconds be required under any conditions to create the standard or least visible tint on the standard medium, it is shown that the surface has an intensity of one octino. Should this tint be secured in 1/64 of that time or in 1 second, then it would be known that the actinicity of the surface equals 64 divided by 1, or 64 actinos. This standard method should be well understood by the reader by this time and is repeated here only for purposes of comparison. In obtaining the actinicity of a surface by the measurement of the light incident upon it, allowance must be made for the difference in what may be termed the *inherent actinicity* of surfaces by reason of their different colors or shades. This is the inherent quality that makes blue more intense than green and white more actinic than gray when in equal light conditions.

Suppose for example that a white, a blue, a yellow and a black cloth be arranged in the same light and that their respective actinicities be measured with the standard meter. The white cloth will be found to be the most actinic and each of the others to measure less than the white in the order named. Should however the light incident upon or *at* these surfaces be measured instead of that emitted from them, it is evident that the color of the surfaces could have no effect on the measurement, since

exactly the same light falls upon each surface and the tinting medium would be turned directly toward that light instead of toward the surfaces.

Considering therefore the incident light, it is evident that one which would suffice to bring a white surface to a one actinic intensity would not create so great an intensity in black, since it may be shown that ordinary black, as of cloth texture, has only approximately 1/16 the actinicity of white in the same light. This being true a black cloth would require to be illuminated with 16 times as strong an incident light as the white one in order to create the same actinicity.

To find therefore the actinicity of any particular surface by measuring the light incident upon it, it is necessary only to find what would be the first appearance time of incident light of such intensity as to bring the surface to one actino.

This time divided by the first appearance time *at* the surface as actually measured in any given case will give the actinicity of that surface in actinos.

This one actino time as referred to above will now be found for different surfaces and given in a table. In working out this table the slower, or factor 8, tinting mediums are used and are recommended to be used in general practise, since, as already explained, the standard medium is too sensitive to be observed with ease in the usual strong light. Should the light be so weak however as to make it advisable to gain time in taking the measurement, as after sunset or in dark interiors, the standard medium may of course be used and its time multiplied by 8, to reduce it to the equivalent p. o. p. time, which is used as the basis of calculation in this problem.

As the four surfaces mentioned above are arranged in the same light, as explained, a standard measurement of the white surface, with the standard tinting medium, results in a time of one second and its actinicity is found therefore to be 64 actinos, since 64 divided by 1 equals 64. Now on measuring the incident light with the slower tinting medium as recommended in this problem, the time is found to be 2 seconds. A two-second incident light time with the slow tinting medium indicates therefore a 64 actino intensity for a white surface and from this it is evi-

dent that had the incident light been twice as strong it would have measured 1 second instead of 2 and the intensity of the white surface would have been 128 instead of 64 actinos. Also it is clear that if a one second incident light first appearance time with a factor 8 tinting medium indicates 128 actinos of intensity for a white surface a 128 second incident light time would indicate an intensity of 1 actino. The one actino, incident light first appearance time with a factor 8 tinting medium is found therefore to be 128 seconds for a white surface.

To illustrate suppose that under certain conditions the first appearance time of the light incident upon a white surface, as measured with solio paper, is 8 seconds: Now it has been found and is a fact that a first appearance time of 128 seconds on such a tinting medium indicated an intensity of one actino in a white surface; therefore a first appearance time of 8 seconds indicated an intensity of 16 actinos $\left(\frac{128}{8} = 16\right)$. That is, a white cloth illuminated with such a light would have 16 actinos of intensity.

Measuring now the blue cloth with the standard meter and medium its actinicity is found to be 32 instead of 64 actinos as for the white cloth. It is evident therefore that twice as strong an incident light would be required to bring it to any certain intensity, say to a one actino intensity, as would be required for the white cloth. From this it is seen that a 64 second first appearance, incident light, as measured with the factor 8 medium, is required to secure a one actino intensity for a blue surface instead of 128 seconds as required for the white surface. As yellow has about one half the actinicity of blue in the same light it is clear that the incident light must be double the intensity of that for blue, or 32 seconds.

To simplify this matter still further for the reader and at the risk of repeating, it may be said that under any condition, as for example in the shade of a house, should the incident light measure 1 second with one of the factor 8 mediums, a white cloth would therefore be known to have 128 actinos, a blue one 64, a yellow one 32 and a red or a black one but 8 actinos of actinicity. It is interesting to note in this connection that since the maximum incident light from the high sun and sky never passes

1/8 of a second on a slow medium, the maximum actinicity of these surfaces can only be eight times as great as that mentioned for a 1 second time, or for white 1M, for blue 512, for yellow 256 and for black 64 actinos.

Here follows the table of incident light, one actino first appearance times as measured with any factor 8 tinting medium, as citrate, disco, solio, etc.

	Incident light time indicating one actino of actinicity	Relative actinicities in same light. Or actinic factors with white as factor 1
White	128 seconds	1
Blue	64 seconds	1/2
Green	32 seconds	1/4
Yellow	32 seconds	1/4
Red	8 seconds	1/16
Black	8 seconds	1/16

As has already been explained the above numbers may also be considered as the actinicities of these different colored surfaces when their incident light measures 1 second with a slow medium. The actinic factors or relative actinicities in the same light are also given.

It must be remembered that the effective actinicity as well as the luminosity of any surface is greatly influenced by the direction from which it is photographed or seen. This follows in accordance with well known laws of reflection. In the analysis of subjects practically, these differences are allowed for in such a way as to make it unnecessary further to consider them, except in certain special lightings in portraiture, as for example in the so called "line" lighting. In this and similar cases the narrow edge or "line" of light is greatly increased in intensity by the angle from which the face is photographed. Here, however, the incident light is measured when the window is arranged as for an ordinary front view lighting, and, while preserving this intensity as the basis of exposure, about half of the incident light is screened away from the face with some opaque screen, care being taken that this screen does not interfere with the light on the reflector which is used for softening the shady side of the face.

To illustrate further, suppose it is desired to photograph some

red roses, and the first appearance time of the light incident upon them (always in the case of incident light it should be understood that a factor 8 tinting medium is used, unless otherwise stated) is found to be 4 seconds; what is their actinicity, and what is their normal exposure in photographing them with a 4 unit diaphragm and using a plate having a speed of 128 seconds or 2 minutes?

It will be noted from the accompanying table that in an 8 second incident light, a red surface has an actinicity of one actino. Now since the incident light is twice as strong as this, measuring 4 instead of 8 seconds, the actinicity of the roses will of course be 2 actinos. Or, by the contrary method, the table shows that for red a 1 second time indicates an intensity of 8 actinos, and a time of 4 seconds, being only 1/4 as strong, indicates only 1/4 of 8, or 2 actinos as before. Now it has already been explained the speed of a plate is the exposure time with diaphragm number one, unit scale, when the actinicity of the surface photographed is one actino. This surface being 2 actinos in intensity, it will require, with the same, or unit diaphragm, one half of the plate speed exposure, 128 seconds, which is 64 seconds. If, however, the 4 unit diaphragm be employed instead of the unit cone, then the exposure will be 1/4 of 64 or 16 seconds. Or, if the 64 unit diaphragm (f-8) be used the exposure will be 1 second, etc.

Again; a newly painted white building is in bright sun light when the sun is high and the day clear; what is its actinicity?

In the paragraph dealing with bright sunlight conditions it will be seen that when the sun is high the first appearance time in the open is 1/8 of a second and that the light value is never greater than is indicated by this time. It will be remembered from the table that a one second time indicates for white an actinicity of 128 actinos and since a time of 1/8 second indicates eight times as strong a light the actinicity of the building will be 8 times 128, which is 1,024 or 1M actinos.

Rule: Divide the actinicity indicated by a one second first appearance time for any colored surface by the time as measured; the quotient will be the intensity of that surface in actinos. Or, divide the characteristic one actino, incident light, first appear-

ance time for any surface by the first appearance time as measured; the quotient will be the actinicity of that surface in actinos.

Problem 4. To find the actinicity of any surface when illuminated by a light source of known actinicity and convergence.

By experiment and calculation it has been found that a surface source of one actino intensity shining at unit convergence (f-64) will create on a white cloth an actinicity of $\frac{1}{16,000}\left(\frac{1}{16M}\right)$ of an actino. Clearly then to find the intensity of the cloth in any light $\frac{1}{16,000}$ should be multiplied by the intensity of that light and again by the cone value of the convergence at a point of the cloth. The result multiplied by the inherent actinicity factor for any color as compared with white as unity will give the actinicity of a surface of that color.

Again, it can be shown by experiment that an average white cloth laid horizontally and lighted by the full sky (direct sunlight being carefully screened) assumes an actinicity of approximately one half of that of the sky itself. So also any such surface illuminated by another expanse large enough to fill practically all the hemisphere of space confronting it takes on one half the average actinicity of the source. From this it follows at once that any light or surface shining on a white cloth at 256 units of convergence (f-4) will create an actinicity that is equal to 1/64 of its own.

THE TECHNIQUE IN PORTRAITURE.

Having considered briefly the logical development of this system and its application to the study of illuminating sources it is now in order to note the technique in one particular class of work, that of portraiture within doors. The system of measurement which the author herewith presents has been practised by him with the very best results.

To take the measurement of the light, expressible in seconds proceed as follows: Place a fresh trip of solio, with the face up, under a convenient hole in a piece of dark card or sheet metal and cover the opening with a coin. Hold the device as near as possible to where the face of the subject is to be placed and

so that the hole exactly faces the light. Then remove the coin, expose 32 seconds and replace; now look at the tint on the solio. It will probably be very pronounced. Pull the strip up slightly and give an exposure of 16 seconds. If the discoloration on the solio is still very plainly visible, give another exposure of 8 seconds; then one of 4 seconds; then one of 2 seconds in order to note the shortest time that will give a just plainly discernible discoloration to the solio. This is the "solio time." Therefore, the "solio time" of any light is the number of seconds it has taken to give a barely discernible tint to the solio paper in that light. On account of the great latitude of most plates, sufficient accuracy will be obtained by taking the solio time as a number in the series 1, 2, 4, 8, 16, 32 seconds; or 1, 2, 4, 8, minutes.

Having determined the "solio time" it follows that for each kind of plate or film used in photography there must be a definite relative aperture which if used with this time of exposure, the plate will be correctly exposed for an average complexion under average conditions. If the plate is slow this "speed diaphragm," as it may be called, is large and vice versa. (I have experimentally determined the speed diaphragms for all plates and films in common use.) For example a Cramer contrast plate is quite slow and has a speed diaphragm of f-8; the slow isochromatic, f-11; crown, f-32, etc. The most rapid plate on the list is the Lumiere sigma with a speed diaphragm of f-64. These could all be read in unit cone values if the shutter diaphragms were scaled in that system. Evidently if a diaphragm other than the speed diaphragm of any special plate in use is desired, the proper time of exposure can be mentally calculated at once.

This method has been slowly taking form in the author's mind for twenty years past and in recent years he has had the assistance of Dr. Arthur W. Goodspeed, professor of physics at the University of Pennsylvania, in arranging the manuscript for publication, a copy of which has been used in a lecture course in that university.

The author is very glad to have found an organization whose business and pleasure it is to search for and systematize these truths, and wishes to express his appreciation of the privilege

of presenting his paper this evening. A great step forward would be the legal establishment of the cone unit for the uniform numbering of lens stops, and that of a practical unit of surface actinicity and it is hoped that this Society may see fit to interest itself in this work.

DISCUSSION.

Dr. P. G. Nutting (Communicated): Mr. Steadman's work on photographic exposure cannot fail to be of service to users of photographic goods. He has put in a practical working form, useful to the layman, the results of the many scientific investigations of the physical properties of photographic materials. Manufacturers of such products are prone to turn a deaf ear to complaints of consumers of waste of time and material in obtaining desired results. Scientific investigators, on the other hand, are content to leave their results in a form not available to the practical man. Manufacturer, investigator and consumer are alike indebted to Mr. Steadman for his comprehensive exposition of the principles of exposure.

The rather comprehensive summary of the theories of exposure and of sensitometry given by Mr. Steadman calls for but little criticism except that references might well have been given to some of the best of the copious literature of the subject for the benefit of those who wish more than a mere working knowledge of the subject. The chief new matter relates to a proposed new unit of lens aperture, a simple method of determining illumination and a simple rule for calculating exposure.

Mr. Steadman's objection that lens stops are not necessarily numbered at their true value is well taken. However, on all the better lenses, stops from F/8 to F/90 are numbered at their true value to within the uncertainty of a setting, and for the larger apertures a recognized convention is observed, for example "F/4.5" is really F/4.7, while F/3.5 is really F/3.7. The higher shutter speeds are also given conventional values, but the time is probably not far distant when some of our leading manufacturers will number all stops and shutters with their true values.

The proposal to adopt a new stop system based on F/64 as a unit I do not favor. There are already several other such sys-

tems in the field; these are all falling into disuse apparently for the reason that lens stops must be marked with their aperture ratios anyway, and makers object to adding any arbitrary scale that is not demanded by the public. It is fully as easy and much more logical to specify an exposure as say "20 seconds at F/16" as in the manner Mr. Steadman suggests.

Mr. Steadman makes no mention of the fact that relative brightness of objects and image depends not alone upon the aperture ratio of the lens, but upon relative distance of image and object (magnification) as well. I give below the complete formula for relative brightness and a brief table to show the importance of the effect. The exact formula for relative brightness (I/I_0) is

$$\frac{I}{I_0} = \pi M \left[M \log \frac{1 + S}{1 + T} - \frac{T}{1 + T} \right]$$

in which

$$M \equiv \frac{1}{1 - m^2} \qquad S \equiv \left(\frac{a}{1 + m} \right)^2 \qquad T \equiv m^2 S$$

m being image distance object distance and a the ratio of focal length to radius of effective lens aperture. Numerical values of $I : I_0$ are given below for

	$m = 0$	$m = 0.1$	$m = 0.2$	$m = 0.5$	$m = 1$	$m = 2$
F/2......	0.190	0.158	0.132	0.0846	0.0491	0.0210
F/5......	0.0312	0.0255	0.0219	0.0130	0.0078	0.0035
F/10.....	0.0078	0.0062	0.0055	0.0035	0.0020	0.0009
F/20.....	0.0020	0.0016	0.0013	0.0009	0.0005	0.0002

In a portrait photographed at half natural size for example, at F/5 the error by Mr. Steadman's calculation is 60 per cent. When m is greater than ½, the neglected part of the formula is greater than the part considered.

Mr. Steadman's discussion of photographic sensitometry is in agreement with Mees and Sheppard's comprehensive and thorough-going book on the subject, and with the writer's book on Applied Optics, Chapter XI, in which is a concise outline of sensitometry and plate grain. He is also apparently unaware that complete Hurter and Driffield tests are made daily in nearly all plants manufacturing sensitive goods.

On the ninth page Mr. Steadman confuses the properties of

hardness and *latitude.* The latitude of a plate relates to the *length* of its scale, hardness to its *steepness.* On the fifteenth page he proposes a new definition of photographic speed. The use of the word in this sense can only add confusion to the already "chaotic" state of photographic practise, since speed in the sense defined by Hurter and Driffield is now universally accepted.

Mr. Steadman uses solio paper to determine intensity of illumination of object much as foresters formerly used a roll of blue print paper in a metal case. A fresh piece is drawn out and the time of appearance of color noted. Many similar instruments are on the market, I believe. A Beck "Lumeter" is a simple, inexpensive, and much more accurate means of quickly determining the luminosity of the object to be photographed. It should be noted that it is luminosity *not* illumination of object, that is required. The use of solio paper as suggested is open to the further objection that this, as well as other classes of sensitive goods, is subject to variations in sensibility of fully 30 per per cent.

Finally, for Mr. Steadman's rule of exposure no advantage can be claimed over the simple rational one in general use,—multiply together plate *inerti*a (H & D), *aperture* ratio squared of lens stop and *luminosity* of low lights of object and divide into a constant. A very serious objection to his rule is that all three factors (plate speed, lens aperture and brightness of object) are defined in new and arbitrary manners thus adding greatly to the chaos of photographic method which he so deplores. Confusion in photographic practise is to be attributed to the widespread ignorance of photographic principles rather than to any lack of logical and precise definition of photographic quantities.

HOME LIGHTING AS SHOWN IN A MODEL APARTMENT.*

BY THOMAS SCHOFIELD

Synopsis: This paper describes in detail the furnishing, decorating and lighting of a model apartment, maintained by a large gas company, as a means of showing what may be accomplished in home lighting with gas, from the standpoints of artistic treatment, convenience and scientific treatment. The lighting equipment is described in detail, accompanied by night photographs of all the rooms and a short resumé of illumination tests run. The author has endeavored to show the importance of the careful treatment of the illumination of the home, but not, however, in a sense of mere efficiency of lighting equipment. Detailed data on the lighting installation in each room is given in an appendix.

The lighting installation herein described is that of the model apartment maintained by the Consolidated Gas Company of New York, on the second floor of the 42nd Street Building at 42nd Street and Madison Avenue, New York.

Nothing has been spared in the designing of this model home to make it attractive, artistic and absolutely complete, and yet well within the limits of practicability, so that the general public may be educated in the essentials of home comfort and hygiene. This is true of the furnishings, decorations, etc., and especially so of the illumination. Therefore the writer believes that any information gathered from this source can well be weighed and considered by those making a study of this branch of the subject of illumination, or by those either about to fit out their homes anew or design new quarters.

While it is truly said, sometimes, that the greatest percentage of a man's waking hours are spent away from home, in the office, factory or store, yet the fact remains that when he does return home at the end of the day's work, he is tired and fagged out from his labors, nervous and fretful over business worries. Therefore should not the greatest attention be paid to the surroundings in which he must place himself while in this condition, and should not an endeavor be made to make them as restful and calming as possible? Again, are not the majority of his hours at home those when the use of artificial light is

* A paper read at a meeting of the New York Section of the Illuminating Engineering Society, January 8, 1914.

necessary. And is there anything more liable to cause irritation, discomfort and positive injury, not only to the master of the house but to the entire family, than a bad or faulty design of lighting equipment? It can readily be seen, then, that this phase of the home's equipment is of very great importance and should be given due serious and conscientious attention in every case.

The apartment consists of six rooms,—reception room, library, dining room, butler's pantry, kitchen and bath room and a private hall having an entrance from the second floor corridor of the building. One walks along this private hall and enters the reception room which communicates directly with the library which in turn opens on to the dining room. Off this last room is found the butler's pantry which leads into the kitchen. The bath room has its entrance from a small hall which is immediately off the reception room, and which contains the entrance from the private elevator, thus completing the apartment.

PRIVATE HALL.

Fig. 1 shows a night view of the entrance hall. The walls are wainscoated in dark brown and red leather and finished off in a brown Japanese straw paper to the white ceiling; the rug is of soft browns, greens and reds; the furniture is of chestnut colored wicker with appropriate colored coverings. With the soft lighting the whole gives that "hint of tranquility" which Emerson demanded in the entrance to the home's inner citadel.

The lighting is accomplished by means of a semi-indirect unit hung in the center of the hall. This fixture is of bronze with light opal art glass, urn-shaped bowl lined and ornamented in bronze. It contains a single inverted incandescent gas mantle unit, which is lighted and extinguished from a wall switch near the entrance. The average intensity of illumination on a plane 30 inches above the floor was found to be 1.02 foot-candles.

RECEPTION ROOM.

Fig. 2 shows a night view of the reception room. Here the prevailing note of the color scheme is deep yellow, which is

carried out in the deep buff rug with blue border, and the chestnut colored wicker furniture with its dark blue coverings—flowered in reds, yellows and greens. The ceiling is white and the wood trim cream, and the room presents a warm cheerful appearance, suggesting comfort and rest.

The lighting is supplied from a large central semi-indirect fixture and one side bracket. The ceiling fixture is of bronze with a whitish glass bowl having its decorations and panelings also in bronze. The side bracket is also of bronze and is equipped with two upright units screened with glass shades. The ceiling fixture contains four inverted incandescent mantle units, and is lighted and extinguished from a wall switch located near the entrance to the room. The side bracket has two small single upright incandescent mantle units. The average illumination on a plane 30 inches above the floor was 2.46 foot-candles.

LIBRARY.

Fig. 3 is a night view of the library. This room is decorated in old English style, and has a high wainscoating of Flemish oak and furniture of the same wood; the walls above the wainscoating are covered with a light brown paper having dark red and green flowers. The furniture is covered with red, green and yellow figured tapestry, and with the red rug and hangings touched with gold, blends perfectly with the other decorations. The ceiling is heavily beamed and finished in cream. A stately mantle, with tiled fireplace, designed especially for this apartment, is located at one end of the room.

In lighting this room special or localized illumination was provided for reading purposes around the centrally placed library table in addition to general illumination throughout the rest of the room. The localized illumination was obtained through a dome of hammered copper and deep amber art glass hanging directly over this table. This dome is equipped with a single inverted incandescent mantle burner which allows enough light to reach the amber glass to illuminate it for decorative purposes, but directs most of its light downward on a diffusing glass plate entirely covering the bottom of the dome. This plate serves as a diffuser of light and also prevents the

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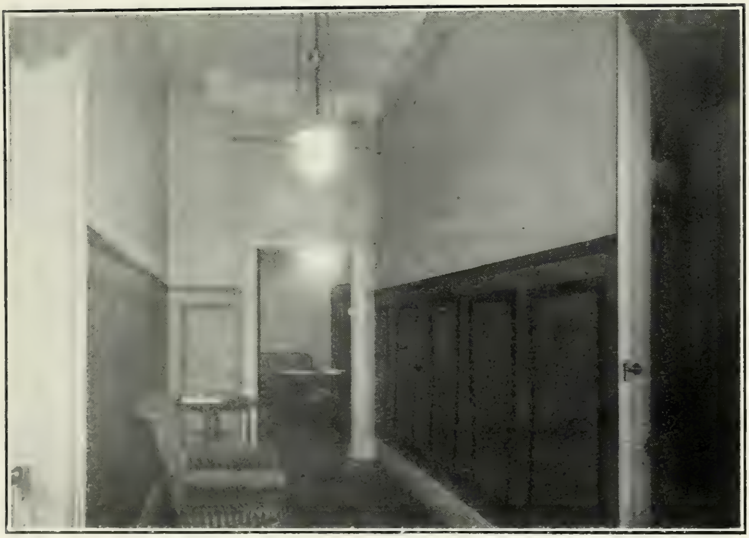


Fig. 1.—Private hall.

Fig. 2.—Reception room.

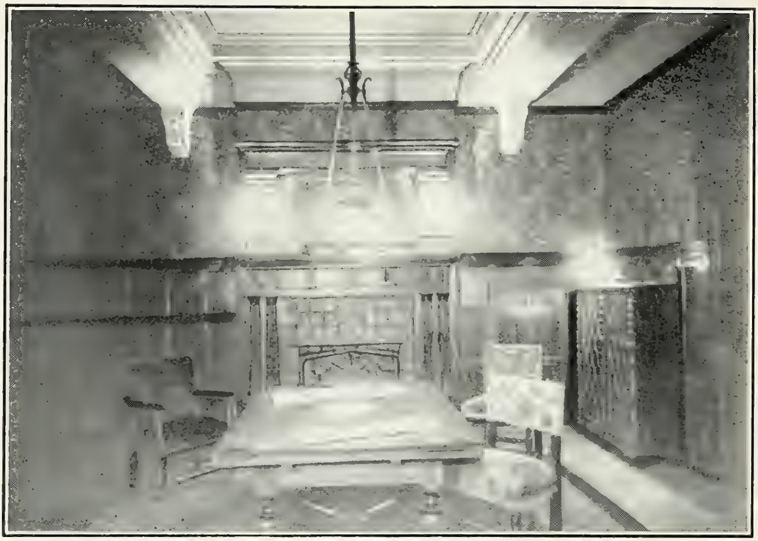


Fig. 3.—Library.

Fig. 4.—Dining room.

light source ever being visible to persons seated around the table. The general illumination is accomplished by means of two copper and deep amber art glass mantle standards, equipped with small single upright incandescent mantle units, and by two side brackets and a book-case lamp, of the same design in copper and deep amber glass, each equipped with small inverted incandescent mantle units, and by a table portable equipped with a single upright mantle unit. The total effect produced is of absolute restfulness and complete comfort. Sufficient illumination is available for all purposes to be met in this room. Another point, well worth mentioning, is the complete harmony of fixtures and decorations and furnishings, a condition too seldom found in the home.

Two illumination tests were made in this room, one for horizontal illumination at the table height over a space directly below the dome and 2 feet longer and wider than the library table, and one for horizontal illumination at the table height throughout the rest of the room. A sufficient number of stations were taken in each test to secure a fair average; three readings on a Sharp-Millar photometer taken at each station. The average local illumination was 2.56 foot-candles. The average general illumination was 0.84 foot-candles.

DINING ROOM.

Fig. 4 is a night view of the dining room. This room is furnished in Colonial style with cream colored woodwork, cream colored paneled ceiling, blue wall coverings and mahogany furniture covered with blue figured hair cloth. The mantle is white with a brick fireplace and is set at one end of the room. In order to carry out the true Colonial period idea—a time when the lighting was done entirely by lamps and candles—the lighting fixtures have been fashioned to resemble old oil lamps. These fixtures consist of a large dome of etched crystal, with hanging fringe of crystal prisms over the dining table, equipped with one upright incandescent mantle burner and controlled from a wall switch. This dome also has its bottom completely closed by a diffusing glass plate thus assuring good diffusion over the table and preventing the bare light source from coming in the line of

vision of those seated at the table. The general illumination of the room is provided by three side brackets fashioned like the dome and each containing a single small upright incandescent mantle unit. This room is another striking example of efficient illumination combined with attractive fixtures in absolute harmony with the decorations and furnishings.

Two photometric tests were made in this room, the first of the illumination on the dining room table top with only the dome lighted, and the second of the average illumination of the rest of the room with all the units burning with a table cloth on the table. A sufficient number of stations were taken on each test to secure a fair average, and three readings on a Sharp-Millar photometer, were made at each station. The average local illumination was 1.66 foot-candles; the average general illumination was 0.66 foot-candles.

BUTLER'S PANTRY.

Fig. 5 shows the butler's pantry with its white tiled floor, enameled tiled wainscoating, white walls, ceiling and cupboards. It is complete in all respects and is lighted by means of a central direct lighting pendant carrying a single mantle inverted lamp with an 8-inch diffusing glass ball, for the general illumination, and a side bracket, over the sink, equipped with a single mantle inverted unit for the local lighting. The control of the ceiling fixture is by a wall switch, and the control of the side bracket is at the bracket itself.

A sufficient number of stations were laid out in this room to obtain a fair average of the illumination, and readings were made of the horizontal illumination at 30 inches above the floor. The average illumination was found to be 3.71 foot-candles.

KITCHEN.

Fig. 6 shows a view of the kitchen. The construction of this room is absolutely perfect from a sanitary view-point. There is nothing which a twentieth century cook could possibly want which cannot be found in it. The floor and walls are tiled in white, and the ceiling is of the same spotless color. The tables are topped with white glass giving no chance for dirt or germs to

Fig. 5.—Butler's pantry.

Fig. 6.—Kitchen.

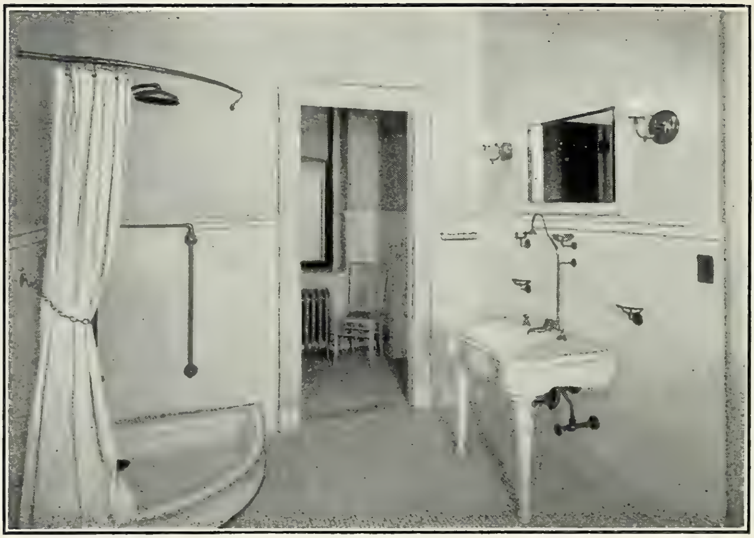


Fig. 7.—Bath room (daylight view).

Fig. 8.—Bath room (night view).

collect. No less sanitary is the lighting. The kitchen is the brightest room in the apartment, which is as it should be, in order to keep as sanitary as possible the place where the food is prepared. Unfortunately this is not the case in the majority of homes. The general lighting is done by a central direct lighting fixture carrying three single mantle inverted units equipped with prismatic reflectors. In addition to this, local lighting is provided by side brackets over the white porcelain sink, over the modern gas range, over the refrigerator and over the side tables, each equipped with a single mantle inverted unit with diffusing glass ball shade.

A sufficient number of stations were laid out in this room to obtain a fair average of the illumination on a horizontal plane 30 inches above the floor. The average of illumination was found to be 6.68 foot-candles.

BATH ROOM.

Fig. 7 shows the bath room by daylight. This room is done in white throughout, with tiled floor and side walls and all nickel fittings. It is complete with tub, shower and wash stand. The lighting is done by two side brackets, in nickel, placed one on either side of the mirror above the wash stand, and equipped each with a small upright mantle unit with prismatic glassware.

Fig. 8 shows a night view taken by the artificial illumination. The average illumination on a horizontal plane was 1.38 foot-candles.

APPENDIX—ROOM DATA.

PRIVATE HALL.

Observed Horizontal Foot-candles.

Station	Foot-candles
1	1.36
2	1.30
3	1.08
4	0.96
5	0.77
6	0.62

Maximum dimensions of hall—17 ft. 9 in. x 6 ft. 8 in.; height of ceiling—12 ft. 2 in.; number of fixtures—1; number of burners per fix-

ture—1; size of burner—No. 6 Reflex; distance bottom of bowl to floor—7 ft. 2 in.; spread of fixture—12 in.; glassware—Equalite; fixture finish—acid bronze; gas pressure—3.70 in.; gas consumption—4.30 cu. ft. per hr.; cu. ft. gas per sq. ft. floor area—0.0364; number of test stations—6; height of test plane—30 in.; average horizontal foot-candles—1.02; lumens effective per cu. ft. gas per hr.—28.04.

RECEPTION ROOM.

OBSERVED HORIZONTAL FOOT-CANDLES.

Station	Foot-candles
1	5.39
2	2.54
3	1.80
4	2.33
5	2.77
6	2.47
7	2.80
8	1.76
9	1.73
10	1.04

Maximum dimensions of room—20 ft. 3 in. x 15 ft. 11 in.; height of ceiling—11 ft. 2 in.; number of fixtures—1 ceiling, 1 side bracket; number of burners per fixture—ceiling 4, side brackets 2; total number of burners—6; size of burners—4 No. 6 Reflex, 2 Welsbach Juniors; distance bottom of bowl to floor—7 ft. 0 in.; spread of fixture—1 ft. 10 in.; glassware—Equalite; height of side brackets—5 ft. 9 in.; fixture finishes—acid bronze; gas pressure—3.70 in.; gas consumption—21.20 cu. ft. per hr.; cu. ft. of gas per sq. ft. of floor area—0.0657; number of test stations—10; height of test plane—30 in.; average horizontal foot-candles—2.46; lumens effective per cu. ft. gas per hr.—37.41.

LIBRARY.

Local Illumination. Observed Horizontal Foot-candles.		General Illumination. Observed Horizontal Foot-candles.	
Station	Foot-candles	Station	Foot-candles
1	2.66	1	1.13
2	2.81	2	0.51
3	2.77	3	0.54
4	1.98	4	0.58
5	2.60	5	0.38
		6	0.68
		7	0.60
		8	1.44
		9	1.24

Local Illumination: Dimensions of space tested—9 ft. 0 in. x 7 ft.

6 in.; height of ceiling 11 ft. 10 in.; number of fixtures—1; number of burners per fixture—1; size of burner—No. 6 Reflex; distance bottom of dome to floor—5 ft. 1 in.; glassware—amber art glass; fixture finish—hammered antique copper; gas pressure—3.70 in.; gas consumption—4.30 cu. ft. per hr.; cu. ft. gas per hr. per sq. ft. area—0.0637; number of test stations—5; height of test plane—30 in.; average horizontal foot-candles—2.56; lumens effective per cu. ft. gas per hr.—40.19.

General Illumination: Area of space—219.0 sq. ft.; number of fixtures—6; number of burners per fixture—1; size of burners—3 Bijou, 2 Welsbach Jr., and 1 No. 71 Welsbach; height of side brackets—5 ft. 11 in.; height of mantle lamps—6 ft. 0 in.; glassware—amber art glass; fixture finish—hammered antique copper; gas pressure—3.70 in.; gas consumption—11.94 cu. ft. per hr.; cu. ft. gas per hr. per sq. ft. area—0.0545; number of test stations—9; height of test plane—30 in.; average horizontal foot-candles—0.84; lumens effective per cu. ft. gas per hr.—15.40.

DINING ROOM.

Local Illumination. Observed Horizontal Foot-candles.		General Illumination. Observed Horizontal Foot-candles.	
Station	Foot-candles	Station	Foot-candles
1	2.75	1	0.58
2	1.34	2	0.75
3	1.34	3	0.65
4	1.34	4	0.72
5	1.48	5	0.75
		6	0.62
		7	0.55
		8	0.48
		9	0.64
		10	0.83

Local Illumination: Area of space tested—15.0 sq. ft.; height of ceiling—11 ft. 0 in.; number of fixtures—1; number of burners per fixture—1; size of burner—No. 71 Welsbach upright; distance bottom of dome to floor—5 ft. 5 in.; glassware—etched crystal; fixture finish—old brass; gas pressure—3.70 in.; gas consumption 4.44 cu. ft. per hr.; cu. ft. gas per hr. per sq. ft. of area—0.296; number of test stations—5; height of test plane—30 in.; average horizontal foot-candles—1.66.

General Illumination: Area of space—289.0 sq. ft.; height of ceiling—11 ft. 0 in.; number of fixtures—3; number of burners per fixture—1; size of burners—Welsbach Junior; height of brackets—6 ft. 3 in.; glassware—etched crystal; fixture finish—old brass; gas pressure—3.70 in.; gas consumption—6.0 cu. ft. per hr.; cu. ft. gas per hr. per sq. ft. area—0.021; number of test stations—10; height of test plane—30 in.; average horizontal foot-candles—0.66.

BUTLER'S PANTRY.

OBSERVED HORIZONTAL FOOT-CANDLES.

Station	Foot-candles
1	2.28
2	2.90
3	3.76
4	4.52
5	5.08

Maximum dimensions of room—11 ft. 5 in. x 5 ft. 11 in.; height of ceiling—12 ft. 2 in.; number of outlets—2 (1 ceiling, 1 side bracket); number of fixtures—2; number of burners per fixture—1; size of burners—No. 6 Reflex; distance ceiling fixture to floor—7 ft. 4 in.; glassware—8 Verre Krasna Ball; fixture finish—acid bronze; height of side bracket—5 ft. 7 in.; glassware—Verre Krasna; fixture finish—acid bronze; gas pressure 3.70 in.; gas consumption—4.30 cu. ft. per hr.; cu. ft. gas per hr. per sq. ft. area—0.0637; height of test plane—30 in.; number of test stations—5; average horizontal foot-candles—3.71; lumens effective per cu. ft. gas per hr.—58.24.

KITCHEN.

OBSERVED HORIZONTAL FOOT-CANDLES.

Station	Foot-candles
1	6.35
2	7.50
3	6.45
4	4.25
5	7.53
6	5.30
7	9.41
8	6.77
9	6.56

Maximum dimensions of room—19 ft. 1½ in. x 18 ft. 9 in.; height of ceiling—12 ft. 2 in.; number of fixtures—5; number of burners per fixture—1 with 3, 4 with 1; size of burners—No. 6 Reflex; distance ceiling fixture to floor—7 ft. 3 in.; glassware—No. 6321 Holophane; fixture finish—acid bronze; height of side brackets—5 ft. 6 in.; glassware—Verre Krasna Balls; fixture finish—acid bronze; gas pressure—3.70 in.; gas consumption—30.10 cu. ft. per hr.; cu. ft. gas per hr. per sq. ft. area—0.084; height of test plane—30 in.; number of test stations—9; average horizontal foot-candles—6.68; lumens effective per cu. ft. gas per hr.—79.45.

BATH ROOM.

OBSERVED HORIZONTAL FOOT-CANDLES.

Station	Foot-candles
1	1.95
2	1.50
3	1.43
4	1.25
5	1.14
6	1.01

Maximum dimensions of room—12 ft. 5 in. x 8 ft. 9 in.; size of burners—Welsbach Junior; height of side brackets—5 ft. 11 in.; glassware—Holophane No. 2404; fixture finish—nickel; gas pressure—3.70 in.; gas consumption—4.0 cu. ft. per hr.; cu. ft. gas per hr. per sq. ft. area—0.037; height of test plane—30 in.; number of test stations—6; average horizontal foot-candles—1.38; lumens effective per cu. ft. gas per hr.—37.43.

DISCUSSION.

MR. J. ARNOLD NORCROSS: I cannot help feeling that a paper of this kind is an inspiration and encouragement to me in my work. I presume that our electrical friends are in the habit of thinking that it is an easy matter to light a modern home well and pleasingly; but it is not so many years ago that I had about given up the idea that gas could be made a successful agent for this purpose. A paper like Mr. Scofield's is bread and butter to me. It shows me what can be done and helps me to go home and do it. It points out the way to utilize that agent of illumination which is at hand, whether it be electricity or gas, to the best advantage and to the satisfaction of the public and the profit of our companies.

MR. C. O. BOND: I think that it would be an excellent thing to put brightness measurements on lantern slides, and if it is not feasible to place many to at least show the lightest spot, the darkest spot and a medium spot, and to indicate these values at the point of greatest contrast. In this way we will be able to find out what does constitute the most pleasant form of lighting, and to explain why.

While the lighting may not be everything that could be desired, all of us will, I believe, recognize that it marks a step forward. It is helpful to see a model apartment, lighted so much better than those to which we are accustomed.

When Mr. Scofield drew that picture of the man coming home worn out by his day's work and ready to be cross at anything, I followed him and felt very sympathetic, but I do not think he went quite far enough. The very fact that you come home indicates that you come home *to* someone. Your wife has I take it, more right to be interested in the lighting of your home and in making it bright and cheerful than you have, and in the presence of the lady guests who are with us to-night I wish to say that I hail the day when the ladies shall begin to show their adeptness in clothing these lighting units so as to make them things of beauty. I believe that they will achieve beautiful and harmonious effects there just as they have done in dressmaking. We have much to look forward to in this way.

Mr. Albert H. Bernhard: I have not prepared any discussion on these papers to-night, but I thought perhaps a few references to European practise might be of interest. I have had most of my experience in Europe, having been employed by a company which controlled both gas and electric undertakings, and those in charge of the electrical department told their men that they must not say anything derogatory about gas. I appreciate very well that, especially in the United States, great progress has been made in developing gas units, because there seems to be much competition. I am an electrical man myself, but I should like to make my position clear to the gas man.

I wish to say, in so far as the Consolidated Gas Company's model apartment is concerned, that it must be taken into consideration that the number of outlets is very much greater than will be found in ninety-nine per cent. of the apartments in New York City. In ninety-five per cent. of the houses you will find just one outlet, whether it has been installed with any regard for utility or not. We cannot change these outlets so long as the National Code is as inflexible as it is at the present time.

In Europe concealed piping is practically unknown. In most cases gas is not allowed to be concealed in the walls at all, and electric light wires are not concealed except in some of the very recent installations. The people there do not wish to spend money on conduit; they consider it to be wasteful. However,

although they want to spend very little money for wiring, they spend a great deal more on fixtures than we do here. Gas lighting on the other side is done by lead piping run exposed on the walls and ceilings, and electric lighting is done by means of silk-covered flexible cord of a color which harmonizes with the furnishings of the room. Under such circumstances, in case the position of an outlet is to be changed, it can be done with very little trouble or expense. You cannot see where a lamp has previously been, because they plug up the small holes left by the supporting screws, and this leaves a very neat installation. There are a great many houses everywhere which have no provision for gas or electric lighting whatever. The installation of these houses might be accomplished, in this country, by using exposed piping for gas; and certainly electric light wiring could be installed by a system similar to the European practise of running exposed cord along the ceilings and down the walls to the snap-switches,—or, if this is not tolerated here, by the use of a molding around the room at the height of the picture molding, with such flexible cord taps to the ceiling as might be required for the lighting of the room. This would be very inexpensive.

Furthermore, the present practise in Europe is to use one lamp in the center of the room suspended on a counterweight cord adjuster, so that the lamp may be moved about at will or left at any height. It can be removed to any part of the room and hooked onto hooks in the side walls, dressers, bedsteads, desks, etc. This allows any part of the room to be electrically lighted at will without more than one outlet being provided, and can be done in such a way as to pass any sort of inspection.

It is surprising to see how much more intelligently they use light in Europe and with a great deal less expense than we do here. They want to make what they do spend for lighting go a long ways.

By the means above referred to, the company with which I was connected was able to put many installations of a few 10 or 15 watt tungsten lamps in apartments where people had not been able to use even gas before. If this company was able to get such results—and it was wonderful to see the effects obtained—as much could certainly be done in this country.

I might mention that I suggested to the manager of the company that an effort be made to supply frosted lamps due to the brilliancy of tungsten lamps as used in Europe. But customers were more attracted by the dazzling light of the naked filaments of the clear lamps. As you probably know, metal-filament lamps can be purchased by the ordinary person in Europe much cheaper than they can here, and they are therefore operated at about 0.8 watt per hefner candle. They cost about 20 cents each over there. Where I was the distribution voltage was about 124, and we used 115 volt lamps and got quite satisfactory life, and we certainly improved the lighting conditions very much and were able to cut down the number of carbon-filament lamps on our circuits to about 30 per cent. when I left to return to New York about two years ago.

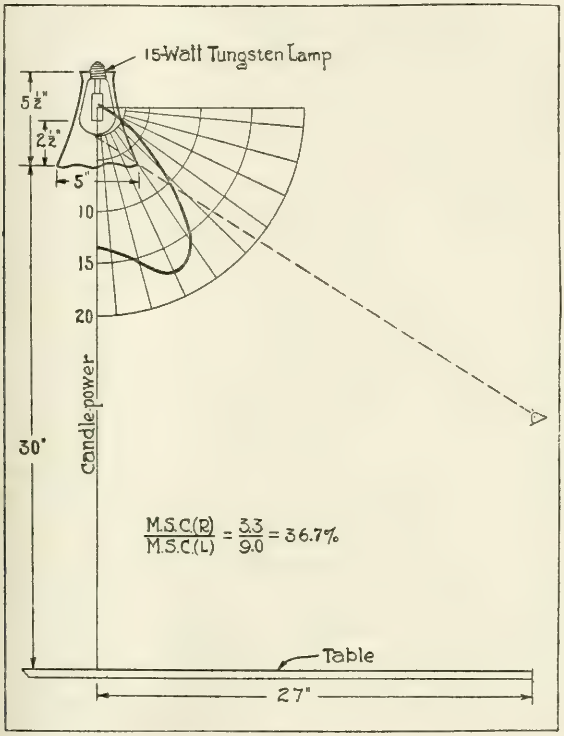
I think one of the gentlemen has already mentioned that the model apartment described in the paper is not an apartment such as people live in where gas is used in New York. I have been in perhaps hundreds of different apartments and certainly have not seen any with as many outlets as shown in the rooms of the gas company's apartment. The pictures illustrating Mr. Powell's paper* come much nearer to showing what is found as a rule. I do not think that there is a kitchen in any apartment in New York City where there are seven outlets installed for lighting, as there are in the gas company's apartment. I do not think such a thing exists. I know the purpose of the model rooms is to show what can be done, but most of the kitchens do not have from five to seven concealed outlets.

Mr. Ward Harrison: The discussion this evening has been chiefly concerned with some form of dome lighting for dining rooms. While this method of lighting is no longer in vogue, I believe that it is the most satisfactory; it gives a reasonable intensity on the walls, and a higher intensity on the table. I note that Mr. Powell* gives 4 feet 9 inches as the height of the dome. I know of two instances where domes were installed and their height above the floor adjusted until it was thought the best position had been obtained. The heights checked within one inch; the average was 4 feet, 3 inches.

In the apartment in which I am living, we use a four-light

* A. L. Powell, "The Lighting of a Simple Home," p. 45, vol. IX (1914).

hower with the lower edge of the reflectors 5 feet above the loor. The reflectors are dense and give an intensive distribution of light. As shown by the curve in the accompanying illustraion, the result is that most of the light is thrown on the table. The reflector is so deep that one cannot see the lamp when seated at the table. The intensity throughout the room is very low; the



effect is pleasing. In illumination results it is similar to the dome inasmuch as the highest intensity is directly below the shower.

In lighting a bath room, a seemingly unsatisfactory installation may be adopted to give adequate illumination. I found an outlet at only one side of the mirror, and the installation of a second on the other side was impracticable. I therefore, installed another mirror so that the lamp came between the two. The arrangement has proved entirely satisfactory.

I believe it is important to provide lighting for all of the clos-

ets. When installed inside, the lamps should always be controlled by door switches. Sometimes one can control the location of outlets in a room so as to bring them opposite the door of the closet and thus provide for its illumination.

In a living room, various intensities are desired at different times. For this reason a flexible system controlled in two or three steps would seem to be most suitable. Such a system is attained in our house by having an indirect fixture in the center of the room supplemented by three table lamps. We have found that with indirect lighting alone, the result did not prove attractive; therefore, we almost invariably use at least one of the table lamps in addition.

One of the speakers brought out the fact that semi-indirect lighting increased the revenue to the central station. I believe that it increases the satisfaction derived by the customer quite as much.

Mr. H. B. Reinach: The relative merits of gas and electric lighting for the home, have been discussed at some length tonight by competent men. It is quite late, so I do not care to add anything more to the discussion. However, I feel that one of the speakers was wrong when he said the average New Yorker does not know the difference between gas and electric lamps. During the past two months the gas company with which I am connected has installed more than sixty thousand Reflex gas lamps in the homes of consumers in New York. The demand is increasing and this campaign is educating the public to the virtues of gas light when used in the modern way.

Mr. Thomas Scofield: The average illumination in the library was approximately 2.5 foot-candles. While no readings were taken to determine the maximum illumination, it probably would be found to be near 3 or 4 foot-candles.

One speaker asked if there were any gas lighted apartments actually being occupied which could have been taken as a subject for this paper. There are thousands of such in the city, and furthermore, the apartment taken is perfectly practical for living purposes with the exception of one drawback, that of the excessively high rent which would be charged due to location of this apartment.

REPORT OF THE RESEARCH COMMITTEE MEETING.

(Held January 10, 1914)

Present: Messrs. Bond, Amrine, Cobb, Langdon, Powell, Richtmyer, Dr. Geo. S. Crampton (by invitation) and H. E. Ives. Letters containing suggestions were received from Messrs. Lancaster, Crittenden and Nutting.

Subject for discussion:

HARMFUL RADIATIONS AND THE PROTECTION OF THE EYES THEREFROM.

The discussion was begun by an attempt to summarize our present knowledge. This brought out at once the necessity of clearly distinguishing between radiations specifically harmful and radiations which have a harmful effect merely because their source (illuminant) is improperly used. Instances were cited where it was probable that investigators worked with lighting installations so poorly arranged that the ill effects quoted might be due partly or wholly to the exposure of the eyes to over-bright light sources.

Another clear distinction necessary to be made is whether the harmful effects take the form of physical injury to the tissues of the eye, or of functional disturbances. A survey of published researches shows that a very large percentage of these deal only with studies of physical injury, such as inflammation, cataract, etc. This has been due in large measure to the fact that tests for functional disturbances, for the effects of cummulative or repeated exposure, are almost unknown.

On taking up the question: "What radiations are harmful"? it developed that a common defect of recorded work is absence of quantitative data. It is often impossible to separate the effects of quality of radiation from quantity or intensity. Sufficient care has not been taken in isolating the radiations of the particular wave-lengths which are supposed to be harmful. Thus in work with ultra-violet light very few experimenters have tried the

effects of ultra-violet radiations alone, *i. e.,* with no visible rays. In many cases the supposedly harmful light sources have had present an enormous preponderance of infra-red or heat radiation. A case in point is "glass workers cataract," frequently ascribed to the ultra-violet light, yet caused (if indeed it is proved to be unduly prevalent among glass workers) by the radiation from furnaces and hot glass overwhelmingly predominant in infra-red.

In spite of these criticisms of many experients on ultra-violet light, there seems to be no doubt that ultra-violet light of certain wave-lengths is intrinsically harmful to the anterior portions of the eye which receive, and by their absorptive characteristics protect, the posterior portions. Functional disturbances due to the cumulative effects of prolonged or repeated exposure are not fully investigated, and one test, that on the time of adaptation, which appears promising, has been made apparently only with total radiation, rich in infra-red.

It appears that the possible effects of infra-red radiation have been somewhat neglected, especially in view of the fact that most artificial illuminants are so rich in heat radiation. Direct physical injury is apparently not to be expected from these rays, unless of such intensity as to actually burn.

Both in the case of ultra-violet and infra-red there appears to be a lack of definite quantitative data on the transmission of the media of the living eye.

Some time was spent in discussion of the amount of ultra-violet and infra-red radiations in ordinary illuminants. Emphasis was laid on the fact that, for the same brightness, most artificial sources have far less ultra-violet than daylight, although much more infra-red. It was however brought out that the difference between the brightness of the illuminant and of most illuminated objects was far greater than is experienced by day, so that these comparative figures might in practise be misleading. Attention was called to the fact that the state of adaptation of the eye for artificial light is different than for daylight and may greatly alter its susceptibility.

The discussion concluded with the subject of protective glasses. In view of the indefinitness of our knowledge as to what radiations are actually harmful, the question of what kinds of glasses

would be protective is not capable of very definite answer. The physical injury due to ultra-violet radiation can unquestionably be stopped by glasses opaque to those rays, so that a simple spectrographic test can determine the good protective glasses. When, however, the actual discomfort or functional disturbance is due to improper distribution, or excessive intrinsic brilliancy, it is doubtful whether protective glasses are the proper remedy. As far as intrinsically harmful radiations are concerned, once we have definite knowledge of what to exclude it is a comparatively simple physical problem to determine the efficacy of a given glass.

A number of problems are suggested as worthy of investigation by those equipped for this kind of work. In suggesting these problems the Committee's indebtedness to suggestions of members of last year's Research Committee is appreciatively acknowledged.

The problems suggested are as follows:

(1) Pathological studies of the effects of infra-red radiation, similar to studies already carried out on ultra-violet light.

(2) A quantitative determination of the transmission of various eye media throughout the visible and invisible spectrum, both in living and dead eyes.

(3) The development of functional tests, suited to show the effects of long continued or occasional exposure.

(4) A pathological study of the possible effects of a cumulative nature which may result from prolonged or repeated exposure to radiations not sufficiently intense to produce immediate harmful effects which can be detected.

(5) An investigation to decide whether the effects of harmful radiations depend upon the state of adaptation of the eye.

(6) To what substance is due the fluorescence of the retina under ultra-violet light?

(7) A study of the adaptation time of the retina as a possible test of functional impairment, and its use with different radiations.

(8) Determination of the specific bactericidal action of various invisible radiations.

In attacking any of these problems special attention should be directed to:

(1) The reduction of all results to definite wave length and energy values.

(2) The clear differentiation between radiations intrinsically harmful and those improperly used.

(3) The necessity for knowing the condition of the eyes used, as shown by proper tests of vision.

The foregoing makes clear that any work on this question must be done with the help of expert judgment, in both its physical and physiological aspects, with respect to the photometric and spectrometric conditions of the experiment on the one hand, and on the other with respect to the physiological and pathological conditions applying to the eye under experimentation. The literature shows that this necessary condition is not always fulfilled.

A partial bibliography of the subject is given below, with the obvious suggestion that no problem should be taken up without a thorough study of previous work.*

Translations of some of the recent foreign papers have been offered for the committee's use by Dr. Crampton. Information concerning these and other matters above discussed will be furnished by the committee upon application.

A set of spectrograms of transmissions of several commercial glasses were furnished by Dr. Nutting and will be kept on file. The correspondence between the various members of the committee and the Chairman, containing in greater detail the material of which this report is a summary will also be on file and may be consulted by interested parties.

HERBERT E. IVES,
Chairman.

* Acknowledgment is here made of the assistance furnished by the very full bibliography contained in Mr. C. B. Walker's survey of the subject.

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Amer. Jour. of Ophth., xiv, No. 12, 353.
Sauer.
Experiments on the visibility of ultra-violet rays. (Experimente über Sichtbarkeit ultravioletter Strahlen.)
Ann. d. Physik, u. Chemie, 1875, clv, 602.
Schanz and Stockhausen.
Ultra-violet light and the eyes (2) also fluorescence of the lens.
Zeitsch. f. Beleuch., Oct. 10, 1907; Aug. 20, 1908.
Protective glasses against short wave radiation.
Arch. f. Augenheilk, lxv, Heft 4.
Schanz, F.
Change and damage in the eye from invisible radiation.
Graefe's Arc. f. Ophth., lxxxvi, p. 549.
Photo-therapy in eye diseases.
Ibid, p. 568.
Changes and deleterious effects of light in the eye. (Veränderungen und Schädigungen des Auges durch Licht.)
Deutsche Med. Wochenschrift, Feb. 29, 1913, xxxix, 345.
Schanz and Stockhausen.
Absorption spectra of the media of the eye.
Arch. f. Ophth., 1908, 69, p. 1.

Injury to the eyes by invisible light.
Gas World, Oct. 26, 1907, p. 507.
Lond. Jour. Gas, Dec. 17, 1907, p. 851.

How are we to protect our eyes from the effects of ultra-violet rays yielded by artificial sources of light?
Illum. Engr., Feb., 1908, p. 898.

Is the effect of ultra-violet light in modern illuminants injurious?
Science Abstracts B, Jan., 1909, p. 36.

Protection for eyes from injurious actions of short-wave rays of light. (Schutz der Augen gegen die Schädigenden wirkungender kurzwelligen Lichtstrahlen.)
Zeitsch. f. Augenheilk., 1910, xxiii, 399.

Has a harmful effect in the eye to be feared from ultra-violet rays of modern illuminants? (Ist durch das ultravioletten Licht der modern Kunstlicthen eine Schädigung des Auges zu befürchten?)
Elek. Zeitschr., 1908, 49.

On the harmfulness and usefulness of our modern light sources. (Uber die Schädlickheit und Brauchbarkeit unserer modernen Lichtquellen.)
Arch. f. Ophth., 1910, lxxv, 403.

Cause of glass-makers' cataract. (Zur Entstehung des Glasmacherstars.)
v. Graefe Arch. f. Ophth., 1910, lxxiii, 553.

Other points on glaring. (Weiterer über Blendung.)
Arch. f. Ophth., 1910, lxxii, 561.

On the fluorescence of the lens. (Uber die Fluoreszenz der Linse.)
Arch. f. Ophth., 1910, lxxiii, H. 1.

On glaring or dazzling. (Ueber Blendung.)
Arch. f. Ophth., 1909, lxxi.

How to protect our eyes against the effects of ultra-violet rays emitted by modern artificial illuminants? (Wie schützen wir unserer Augen vor die Einwirkung der ultravioletten Strahlan unserer Kunstlichen Lichtquellen?)
Arch. f. Ophth., 1909, lxix, 49.

Protection of industrial workers from blinding. (Schütz gewerblicher Arbeitern gegen Blendung socialeo.)
Medizin und Hygine, 1909, iv, 403.

Action of ultra-violet light on eyes. (Die Wirkung der ultravioletten Lichtstrahlen auf das Auge.)
Berlin klin. Wochenschr., 1909, No. 21.

On the effects of ultra-violet light upon the eyes. (Über die Wirkung der ultravioletten Strahlen auf das Auge.)
Arch. f. Ophth., lxix, 452.

Aspect of the evil effect or injuries in the eye by bright and ultra-

violet rays. (Zur Beurteilung der Schädigung des Auges durch leuchtende und ultraviolette Strahlen.)
Klin. Monatsbl. f. Augenheilk., 1909, N. F. viii, 442.
Injuries to the eye caused by the effect of ultra-violet light. (Die Schädigung des Auges durch Einwirkung des ultravioletten Lichtes.)
Electro. Zeitschr., 1908, xxxiii, 777.
How to safeguard our eyes from the effects of ultra-violet rays. (Wie schützen wir unserer Augen vor der Einwirkung der ultravioletten Strahlen.)
Klin. Monatsbl. f. Augenheilk., 1907, 454.

SCHANZ.
On the alterations in and damages to the eye due to invisible rays of light. (Uber die Veränderung und Schädigungen des Auges durch die nicht direct sichtbaren licht Strahlen.)
Deutsche Beleucht. Gesell., Nov. 8, 1913.

SCHOTT AND GEN.
Ultra-violet rays and the eye.
G. S. File, No. 25, 10.
Are ultra-violet rays harmful?
Gas World, Oct. 22, 1910, p. 487.

SCHULIC.
Protective eye-glasses against ultra-violet rays as found on basis of photological studies. (Schutzbrillen gegen Ultraviolett auf grund photologischer Studien.)
Beitr. z. Augenheilk, 1900, ii, 467.

SEABROOK, DR. H. H.
Effects of light upon the eye.
Amer. Gas Jour., Jan. 27, 1908, p. 140.

SEKULIE.
Ultra-violet rays are directly visible. (Ultraviolette strahlen sind unmittelbar sichtbar.)
Ann. d. Physick. u. Chemie, 1872, cxlvi, 157.

SETSCHENON.
On the fluorescence of the retina. (Ueber der Fluoreszenz der Retina.)
v. Graefe Arch. f. Ophth., ii, 204.

SMITH, PRIESTLY
A scotometer.
Ophth. Soc. of Un. King., March 8, 1906, Ophth. Review, 1906-155.

SORET.
Researches on the absorption of ultra-violet rays. (Recherches sur l'absorption des rayons ultravioletts.)
Arch. d. Sc. Phys. et. Naturelles, 1883, X, 429.
On the absorption of ultra-violet rays by the media of the eye

and some other substances. (Sur l'absorption des rayons ultravioletts par les millieux de l'oeil et par quelques avtres substances.)

Comptes Rendus, 1893 xcvii, 572.

On the transparency of the eye media to ultra-violet rays. (Sur la transparence des millieux de l'oeil pour les rayons ultra-violetts.)

Comptes Rendus, 1879, lxxxvii, 1012, 1015.

On the visibility of ultra-violet rays. (Sur la visibilite des rayons ultraviolettes.)

Comptes Rendus, 1893, xcvii, 314.

ORSCHKE.

Studies on the impairment of the visual power by blinding. (Untersuchungen über die Herabsetzungen der Sehschärfe durch Blendung.)

Zeitschr. f. Phys. d. Sinnesorg, 1904, Bd. 34, u. 35.

TAERKLE.

On the harmfulness relative to the eye of modern sources of light and their field of application. (Ueber die Schädlichkeit moderner Lichtquellen auf das Auge und deren Verbreitung.)

Arch. f. Augenheilk, 1904, I. 12.

TAHLI, JEAN

On investigation of the eye with the Nernst light.

The Ophthalmoscope, Dec. 1913, p. 736.

TEINMETZ, C. P.

The physiological effects of radiation.

Trans. I. E. S., Oct., 1909, p. 683.

TERN AND HESSE.

On the effect of violet light on the skin. (Ueber die Wirkung des Violettlichtes auf die Haut.)

Muchen Med. Wochenschr., 1907, 318.

TOKES.

Philosophical Transactions.

1852, No. 73, 558.

TOCKHAUSEN.

Illumination of working places and workshops. (Die Beleuchtung von Arbeitsplatzer und Arbeitstraumen.)

Naturforscher, Vers Dresden. 1907, Ophth. Sektion, 2. Sitzung.

Glaring, its causes and effects. (Blendung ihre Ursache und Wirkung.)

Zeitschr. f. beleuchtungsw., 1910.

Illumination and the eyes.

Gas World, Aug. 6, 1910, p. 161.

STRAUSS.

Results of treatment of skin diseases with uviol light. (Resultate der Uviollicht Behandlung bei Hautkrankheiten.)

Dermat. Zeitschr. 1907, xiii, H. 11.

STROBEL.

Exposure to iron arc.

Klin. Monatb. f. Augenheilk.

STUBEL, HANS

Fluorescence of animal tissues in ultra-violet light.

Pfluges. Arch. f. d. Ges. Physiol., Vo. 142, p. 1, 1911.

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Prognosis of visual troubles of an electric origin. (Du prognostic des troubles visuels d'origine electrique.)

Ophthalmic electrique.

Arch. d'ophth. xiii, 1.

TIGERSTEDT.

Limits of visibility of spectrum. (Die Grenzen des sichtbaren Spektrums.)

Biophysik. Centralbl., 1905, 1, 1-4 and 33-38.

TYNDALL.

Light. (Das Licht.)

Dutsche Ausgabe. Braunschweig. 1876, 177-192.

VOGT.

Causation and nature of erythropsy. (Ursache und Wesen der Erythropsie.)

Bericht. d. Ophth. Ges. Heidelberg, 1908.

Safeguarding the eye against effects of ultra-violet rays from bright sources of light by means of a new, almost colorless brand of glass. (Schütz des Auges gegen die Einwirkung ultravioletter Strahlen grelle Lichtquellen durch eine neue, nahezu farblose Glassart.)

Arch. f. Augenheilk, 1907, lix, 48.

Critique of treatises and lectures by Schanz and Stockhausen, and Best, with experimental researches on fluorescence of the lens, blinding erythropsy and blinding exanthropy. (Kritik der Abhandlungen und Vorträge von Schanz und Stockhausen und Best nebst experimentellen Untersuchungen uber fluoreszenz der Linse, Blendungerythropsie und Blendung exanthropsie.)

Arch. f. Augenheilk, 1904, lxiv, 4.

Experimental investigation on the permeability of the transparent media of the eye for the ultra-red portion in artificial light sources.

Von Graefe's Arch. f. Ophth. Bd. lxxxi, Heft, i, 13, Feb., 1912.

VALOIS.
Electric ophthalmia. (Ophthalmic Electrique.)
Clinique Ophth., 1904, 92.

VOSSIUS.
A case of ophthalmia electrica. (Fall von Ophthalmia electrica.)
Berlin Klin. Wochensch, 1886, 304.

VOEGE.
Is damage to the eye to be feared from the ultra-violet rays of modern artificial light sources (Ist durch des ultravioletten Licht der modernen kunstlichen Lichtquellen eine Schädigung des Auges zu befürchten?)
Electrosch. Zeitschr, 1908, No. 33.

Marginal notes on Schanz' and Stockhausen's treatise on the action of ultra-violet rays in the eye. (Bemerkungen zu den Aufsatz Schanz und Stockhausen uber die Wirkung der ultravioletten Strahlen auf des Auge.)
Arch. f. Ophth., 1908, lxx, 403.

Ultra-violet rays of artificial illuminants and their alleged harmfulness for the eye. (Die ultravioletten Strahlen der kunstlichen Lichtquellen und ihre angebliche Gefär fur das Auge.)
Verlag. von J. Springer, Berlin, 1910. 14.

Is there danger to the eyes from the ultra-violet light of modern illuminants?
Science Abstracts, Sept., 1908, p. 434.

Ultra-violet rays and heat radiation.
London Ill. Engr. Aug., 1913, p. 440.

Spectral distribution of various lights and glasses for protection.
Electrotech Zeitsch. 1909, Vol. xxx, p. 512.

The radiation of our artificial light sources in comparison with each other and with daylight.
Licht und Lampe, Mar. 27 to Jul. 17, 1913.

VOEGT, A.
Effect of ultra-violet rays on the eyes.
Elec. World, Apr. 28, 1910, p. 1076.

Experimental researches on the penetrability of the transparent eye media for ultra red rays of artificial illuminants. (Experimentelle Untersuchung über die durchlässigkeit der durchsichtigen Augenmedien für das ultrarot Kunstlichen Lichtquellen.)
Graefes Archiv. f. Ophth., 81, 1912, p. 153.

VOEGEL.
Photo-therapeutics in practical electrotechnics. (Lichttherapie in

prakt. elektrotechnick.) (Among other things discusses therapeutic value of various spectral regions.)
Electrotech. Zeitsch., Jan. 14, 1909, xxx, p. 32.

WALKER, CLIFFORD B.
The effect of ultra-violet rays on the eye. An essay submitted to the Board of University Studies of Johns Hopkins University, in conformity with the requirements for the Degree of Master of Arts, with extensive bibliography.

WIDMARCK.
On the pathological effect of intense illuminants upon the eye. (Von den pathologischen Wirkung starken Lichtquellen auf das Auge.)
11 nord ophth. vers. Kopenhagen, 1903.

On the action of light on the lens. (Uber die Einfluss des Lichtes auf die Linse.)
Mitteill, aus d. Augenheilk, d. Carol. Med. Chir. Inst. zu Stockholm, 1901.

On the influence of light upon the anterior media of the eye and skin, on the permeability of the eye for ultra-violet rays. (Ueber den Einfluss des Lichtes auf die vorderen Medien des Auges—und Haut—ueber die durchlässigkeit der Augen fur ultraviolette Strahlen.)
Beitrage zur Orphth., Leipzig, 1891, 355-502.

On the blinding of the retina. (Ueber Blendung der Netzhaut.)
Skand. Arch., 1893, iv, 28.

On the impenetrability of the eye media relative to ultra-violet rays. (Ueber die durchdringlichkeit der Augenmedien fur ultraviolette Strahlen.)
Skand. Arch. f. Physiol., 1891, III, 14-10.

On the transparency of the eye media relative to ultra-violet rays. (Ueber die Durchdringlichkeit der Augenmedien fur u. v. Strahlen.)
Skand. Arch. Physiol., 1892, 3-14.

Limit of visibility of spectrum at the violet end of the same. (Uber die Grenze des sichtbaren Spektrums nach der violetten Seite.)
Mitteil, aus der Augenheilk zu Stockholm, 1898, I, Jena, 31.

Action of light on the anterior media of the eye. (Ueber den Einfluss des Lichtes auf die vorderen Teile des Auges.)
Skand. Arch., 1889, I. 264.

Effect of light upon the anterior portions of the eye. (Uber den Einfluss des Lichtes auf die vorderen Teile des Auges.)
Nord. Med. Ak., 1889, xxi.

WILLIAMS, CHAS. H.
Observations of the effect of the light of the mecury arc lamp on the eye.
Elec. World, Sept. 2nd, 1911, p. 550.

WYDLER, V.
Experimental researches upon after-image due to dazzling and their relationships to dazzling erythrepsia.
Zeitschrift fur Augenheilk, May and June, 1912.

ZACHIMMER.
Discussion of lecture of Schanz and Stockhausen held on the Erfurt meeting of electrotechnicians. (Diskussion zum Vortrag Schanz und Stockhausen auf der elektrotechniker Versammlung in Erfurt.)
Electrotecher Zeitsch, 1908, 648.

ZERNY.
Dazzling of retina by direct sunlight. (Ueber Blendung der Netzhaut durch direktes sonnenlicht.)
K, Akad. d. Wissensch., Oct., 1876, vi.
Sitz. d. Wiener Acad., 1867, lxi.
Illumination and the eye.
Illuminating Engineer, (London), Sept., 1913, p. 451.
Dangers of certain electric lamps; physiological action of violet and ultra-violet rays.
Review Jnl. des Usines a Gaz, Nov. 20, 1913, p. 347.
How to neutralize the sight imparing effects of electric lamps.
Editorial Lond. Jnl. Gas. Ltg., Jun. 4, 1912, p. 628.
The sensitiveness of different eyes to ultra-violet light.
Editorial Lond. Ill. Engr., Sept., 1910, p. 559.
Effect of ultra-violet rays on the eye.
Scien. Am. Supp., Sept. 17, 1910, p. 183.
Ultra-violet rays and disease.
Lond. Ill. Engr., Dec., 1909, p. 838.
Effect of blue and ultra-violet rays on the eye.
Gas World, Sept. 19, 1908, p. 330.
Some effects of light visible and invisible.
Lond. Ill. Engr., Sept., 1908, p. 763.
Electric light and eyesight.
Lond. Jnl. Gas Ltg., Apr. 14, 1908, p. 95.
Narcosis by blue rays of light.
Ill. Engr., Dec., 1907, p. 751.
Discussion of work of Voege.
Editorial Zeitsch f. Beleuch., Jan. 10, 1911, p. 1.
Artificial lighting and ultra-violet rays.
Review of work by Schanz and Stockhausen.
Lond. Jnl. Gas Lyg., Jun. 22, 1909, p. 893.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 3, 1914

PART II

Miscellaneous Notes

Council Notes.

regular meeting of the Council
ıeld in the general offices of the
ty, 29 West 39th Street, New
March 12, 1914. Those pres-
vere: C. O. Bond, president; C.
ittlefield, V. R. Lansingh, Alten
ller, Preston S. Millar, J. Arnold
oss, F. J. Rutledge, George H.
ıey, and E. J. Edwards as the rep-
ative of Ward Harrison.

minutes of the February Council
ıg were approved as printed.

Finance Committee reported that
l set aside from its annual ap-
ations the following moneys:
oo for framing the pictures of
ast presidents of the Society;
for the expenses of the member-
ampaign; $15.00 for the framing
t Convention photographs; $66.00
er excess expenditures from the
of $300.00 collected for the Light-
xhibit Committee; $25.00 towards
penses of the Gas Congress.

eport from the general secretary
d a net gain of 52 members in
embership since the first of the
year, October 1, 1913; nine sus-
members have been elected. The
ıembership, including the applica-
ınd resignations presented at the
meeting of the Council and 32
ing members, was 1,489.

t applicants whose names appear
ere in this issue of the TRANSAC-
were elected members of the
y.

r resignations from membership
ccepted.

nformal report was received from
embership Committee, outlining a
ign for new members which is
started shortly. The plans were
ed by the Council. It was understood that the Committee will make a further report before the campaign is actually started.

It was voted to forward all monthly reports of the Research Committee to the Papers Committee just as soon as they are received.

A written report was received from the Committee on Editing and Publication. In accordance with this report the following recommendations in connection with the publication policy of the Society were adopted:

(a) Hereafter there will be published in the TRANSACTIONS announcements of new books dealing with illuminating engineering. It was also suggested that the Committee on Editing and Publication compile a list of books published since the organization of the Society.

(b) In each issue of the TRANSACTIONS a list of current articles on various phases of illuminating engineering will also be published. This list is to be supplied by the Progress Committee.

The Section Development Committee reported that it had under consideration the policy of the sections holding joint meetings with other organizations. A definite report will be made later.

Written reports on progress of section activities were received from Messrs. J. W. Cowles and W. J. Serrill, vice-presidents of the New England and Philadelphia Sections respectively. Mr. G. H. Stickney reported verbally on the activities of the New York Section.

Mr. Stickney reported verbally on the work of the Papers Committee.

The resignation of Mr. G. H. Stickney as chairman of the Popular Lectures Committee was accepted at his request.

The resignation of Mr. L. B. Marks as representative of the Society to the

Committee on Organization of the International Gas Congress, and to the United States National Committee of the International Commission on Illumination was accepted at his request.

Mr. J. Arnold Norcross was appointed to succeed Mr. Marks as representative of the Society on the Committee on Organization of the International Gas Congress.

The Council also accepted the resignation of Dr. E. P. Hyde, at his request, as delegate of the Society to the United States National Committee of the International Commission on Illumination.

Mr. Preston S. Millar was appointed to succeed Dr. E. P. Hyde.

Mr. G. B. Nichols was appointed a local secretary of the Society in the City of Albany, N. Y.

The following committee appointments were confirmed:

National Membership Committee: E. B. Rowe, H. B. McLean and F. H. Murphy.

The General Convention Committee consists thus far of the following members: W. M. Skiff, chairman; Geo. S. Barrows, J. W. Cowles, Clarence L. Law, and C. A. Luther.

The Committee on Booth Displays (Electric) was authorized to prepare an exhibit to be displayed at the Electrical Show in Cleveland. It was understood (a) that these booths would at the close of the show be acquired by the Committee and that arrangements would be made to have them exhibited at other shows, meetings, etc. (b) that these booths would be loaned to various central stations and others for temporary display; (c) that the Committee would submit to the Council a schedule showing the dates and places where the exhibit would be displayed before the booths were started on their itinerary; (d) That the booths would be acquired and shipped from place to place at no expense to the Society.

Mr. Millar reported on the cost of preparing a lighting exhibit for display at an exposition which is to be held in New York during the month of April under the auspices of the Ethical Culture Society. It was voted that the Illuminating Engineering Society communicate with the Ethical Culture Society stating the willingness of the I. E. S. to supply such an exhibit provided the E. C. S. would contribute $50.00 towards the expenses connected with the work.

It was resolved that it is the sense of this Council that it would be inexpedient to hold the 1915 Convention of the society in San Francisco, Cal.

The following By-Law received a first reading:

All representatives or delegates to conventions or other similar bodies, when appointed by the President and approved by the Council, shall be considered as automatically holding office until their work on such conventions shall have ceased, unless the next President subject to the approval of the Council, shall make other appointments. Such representatives or delegates may be at any time replaced by other representatives or delegates on appointment by the President and approval by the Council. All actions by such representatives or delegates must first be approved by the Council before becoming binding on the Society. This by-law however does not apply to representatives or delegates to other societies or bodies, the work of which by its nature continues indefinitely.

Section Activities

CHICAGO SECTION

The Chicago Section held a meeting in the auditorium of the Western Society of Engineers, Monadnock Block, Chicago, Ill., March 11. Charles A. Luther of Chicago read a paper entitled

e Lighting by Gas." A second on "Home Lighting by Elec-' was presented by Mr. Philip ieck of Milwaukee. Mr. Wm. A. ı gave the third of his series of -minute talks on "The Funda-s of Illumination."

Chicago Section participated in a l meeting of engineering and :al societies which was held in ukee, Wis., March 21. Two on lighting were read at the g: "Principles of Street Lighting" ssrs. A. J. Sweet and Francis A. n; "Principles of Illumination" hn Hayes Smith. Six hundred were in attendance.

oint meeting was held with the ıy Signal Association, April 10, e auditorium of the Western y of Engineers. The following were presented: "Illumination ailway Signals" by Thos. S. s; "Physiology of the Eye and lation to Signal Affairs" by Dr. ı M. Black; "Signal Lenses" by . P. Gage, Corning Glass Works, ıg, N. Y. Fifty members and were present.

NEW ENGLAND SECTION

ch 27 a joint meeting of the New ıd Section and the National Com-l Gas Association was held in yan Hall, Boston, Mass. A paper d "Recent Advances in Gas Light-vas presented by C. W. Jordan of hotometrical Laboratory of the l Gas Improvement Company, lelphia, Pa. Following the pres-on of this paper was a supple-ry discussion of a system of dis-control of gas lighting by H. E. en. About one hundred and -five members of both societies present.

NEW YORK SECTION

The New York Section held a meeting March 12 in the Engineering Societies Building. Mr. Bassett Jones presented a paper entitled "Color in Light" with special reference to display and show window lighting. The paper was supplemented with lantern slides, a color booth, a model show window and a new device for calibrating lighting equipments where color is used. Two hundred members and guests were present. At an informal dinner at Murray's on West 42nd Street preceding the meeting forty members were present.

A joint meeting with the American Museum of Safety was held in the Engineering Societies Building April 9. Four papers were presented: "Glasses for Protecting the Eyes in Industrial Processes" by Mr. M. Luckiesh; "Illumination as a Factor of Safety in Industrial Plants" by R. E. Simpson; "Railway Yard Lighting as a Factor of Safety" by I. W. Ensign; "Some Reasons Why Red is not a Proper Color for Danger Signals" by Dr. Wm. Churchill. About two hundred people attended. At the usual informal dinner, which preceded the meeting at Murray's on West 42nd Street, thirty members were present.

PHILADELPHIA SECTION

The Philadelphia Section held a regular meeting March 20 at the Engineers' Club. The paper of the evening "The Sun: The Master Lamp" was presented by Prof. James Barnes of Bryn Mawr College. Fifty members and guests were present.

Arrangements have been made for a meeting and smoker of the scientific and engineering societies of Philadelphia, at the Continental Hotel Roof Garden, May 15. Seventeen societies

and the Philadelphia Section will participate in the meeting. Included in the program of the meeting is an address by Dr. Chas. Proteus Steinmetz on "The Relation of Engineers to the Progress of Civilization."

At a meeting held in the Franklin Institute, April 9, Mr. Preston S. Millar presented a paper entitled "Recent Developments in the Art of Illumination." One hundred and fifty members and guests were present.

PITTSBURGH SECTION

A meeting of the Pittsburgh Section was held March 13 in the auditorium of the Engineers Society of Western Pennsylvania. Two papers were presented: "Modern Gas Lighting" by C. W. Jordan, United Gas Improvement Company, Philadelphia, Pa., and "Gas Arc Lighting" by S. B. Stewart of Consolidated Gas Company, Pittsburgh, Pa. A number of gas arcs were used to demonstrate the papers.

At a meeting in the auditorium of the Engineers Society of Western Pennsylvania, April 17, the following papers were read: "The Development of Flame Carbon Arc Lamps" by C. E. Stephens of the Westinghouse Electric & Manufacturing Company; "The Firefly and Other Luminous Organisms" by Prof. F. A. McDermott of the University of Pittsburgh. Prof. McDermott's paper was accompanied by a number of demonstrations showing by means of chemical experiments the reactions taking place in the firefly's method of producing light. Mr. R. B. Chillas of the National Carbon Company, Cleveland, gave a talk on "The Development of the Flame Carbon." Fifty-four members and guests attended the meeting.

The next meeting will be held in Cleveland, May 15.

New Members.

The following applicants were elected members of the Society at a meeting of the Council held March 12, 1914:

ATKINSON, KERR.
Instructor in Elec. Eng., Engineering Bldg., University of Missouri, Columbia, Mo.

CRAMPTON, GEO. S., M. D.
Ophthalmologist, 1700 Walnut St., Philadelphia, Pa.

CROSBY, HALSEY E.
Chief Electrician, Columbia University, Morningside Heights, New York, N. Y.

DAY, DAVID T.
Chem. Geologist, United States Geological Survey, 1330 F Street, Northwest, Washington, D. C.

GORING, G. H.
Sales Agent, Hamilton Electric Light & Power Co., Ltd., Hamilton, Ontario, Canada.

LUKENS, GEORGE N.
General Manager, N. Y. & Foreign Sales, Macbeth-Evans Glass Compnay, 143 Madison Avenue New York N. Y.

MONOGHAN, J. F.
Salesman, Horn and Brannen Mfg. Co., 427 N. Broad Street, Philadelphia, Pa.

SCHNEIDER, JOHN J.
Dr.—Ing. Schneider & Naujoks, Elektrizitäts-Ges. M. B. H., Rebstöckerstrasse 55, Frankfort-a-Main, Germany.

Index for Vol. VIII.

The index for Volume VIII (1913) of the Transactions is mailed with the present issue of the TRANSACTIONS.

Eighth Annual I. E. S. Convention.

The eighth annual convention of the lluminating Engineering Society will be eld in Cleveland, O., during the week of September 21, 1914. It is likely that the sessions will be held during the first part of the week and take about four days.

TRANSACTIONS
OF THE
Illuminating Engineering Society

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VOL. IX NUMBER 4 1914

REPORT OF THE RESEARCH COMMITTEE.

(Meeting held February 7th, 1914.)

Present: Messrs. Amrine, Bazzoni, Crampton, Ferree, Langdon, Powell, and H. E. Ives.

Letters on the topic for discussion were received from E. J. Edwards and E. B. Rowe.

The subject for discussion at this second meeting of the Research Committee was:

THE ANALYSIS AND CLASSIFICATION OF ILLUMINATION SYSTEMS.

The subject was considered chiefly from the standpoint of laboratory analysis, having in mind the physical factors which should be considered by the physiological and psychological investigator of lighting problems. Into what fundamental factors can an illumination system be resolved for study, and how shall these be measured and recorded in order that the exact working conditions may be understood or duplicated?

Following this analysis considerable time was directed to discussing definitions of "direct and indirect lighting systems."

The scientific analysis of a lighting system is completely given by a record of the intrinsic brilliancies of all objects visible from the position chosen for test, and by the components of illumination at all points. For an absolutely complete description of the lighting conditions the number of measurements would be very large. In any given case by attention to the more significant points and the exercise of judgment the number may be greatly reduced. Also, while every factor is actually given by these data, a more concrete idea may often be obtained from

more obvious characteristics, such as the general direction of the light, the area of the principal light source, whether it is visible or invisible to the observer, and in other cases by the commercial specifications.

Treating these factors in greater detail:

Intrinsic brilliancy, or candle-power per unit of area. A complete plot of the intrinsic brilliancies of all visible areas constitutes a picture of the image thrown upon the retina. In many cases this gives all the necessary information. These measurements should be plotted upon a dimensioned drawing, or, even better, upon a photographic print. All points cannot, of course, be so given, but special attention should be paid to the extremes; to the bright light sources and to their backgrounds; to the adjacent spaces of greatly different brightness. The method of making contour maps by the surveyor might be taken as a guide to what is called for here.

Components of illumination.—The number of components of illumination at a point is infinite, and the number of points and planes upon which measurements can be made is infinite. In any given case the points or planes of chief interest must be selected and the illumination components determined in the smallest number of directions which will give an adequate idea of conditions. Thus in much illuminating engineering work the horizontal plane 30 inches (0.76 m.) above the floor is chosen for measurement, as being desk and table height; but other planes often figure, as in library lighting, where the plane of the bookcase is of chief interest. The number of components to be measured is determined by the kind of test or work. If the test involves only flat surfaces, such as print, the measurement of intrinsic brilliancy or of normal illumination is sufficient. If relief surfaces, such as type, then the direction of light becomes significant. In any case the greatest number of components likely to be of interest at the point of work is nine, namely, vertical, four at 45°, four horizontal.

As to the other factors actually covered by these measurements, but capable of supplying significant information immediately, some are in greater detail, as follows:

Visibility of light sources.—The illumination of the floor and

ɔwer part of the room by daylight is frequently from a part of he sky not visible to the occupants of the room. The illumina-ion of a working plane may be entirely unaffected by the inter-osition of a shade between the light source and the observer, ut the visibility or invisibility of the illuminant is of interest to ıe worker. Consequently the concealment or visibility of the ght source is a significant factor and is easily recorded. By light source" must be understood, in illumination science, not lone the original illuminant, such as the flame or filament, but ıe surface from which the light comes, either by emission, dif-use reflection or diffuse transmission, which illuminates the oint of study. Thus the bright ceiling used with an "indirect" nit is the light source to be considered in discussing visibility r concealment, not the lamp in the fixture.

The terms "primary light source" and "secondary light ɔurce" may be used if desired to distinguish between the riginal illuminant, and the reflecting and transmitting acces-ɔries which as well illuminate the point of study.

Area of light source.—The character of the shadows and the elative value of different components of illumination is con-itioned largely by the angle subtended by the principal light ɔurce. The mere statement that the light sources are practi-ally points (as in the case of bare incandescent lamps) or areas f several square meters (when a bright ceiling is used) is of alue.

Direction of light.—Usually the light falling on the working lane comes largely from a definite direction from above or from ne side. Since certain kinds of detail are revealed by one irection of light over another, this is a factor of importance. Esthetic values are affected to a marked degree by the direction f shadows, and as a consequence the general impression pro-uced on an observer is dependent on the direction of light.

Dimensions and commercial specifications.—No details of di-ıensions or position which are necessary for the complete pic-uring of conditions should be omitted. The use of commercial pecifications of illuminants, auxiliary apparatus and illuminated urfaces frequently saves much time, but it must not be forgot-

ten that such specifications are apt to be of significance only locally and for a limited time. The legitimate use of photographs with dimensions to show details of shape and position, and of photographs on which measurements of surface brightness are marked to show brightness distribution is to be encouraged.

SUBJECTS FOR STUDY.

The suggestion is made that investigations of lighting conditions from the standpoint of physiology and psychology, the study of methods of tests for effects upon the eye, etc., should be initially made upon the simple component factors which in combination produce all the retinal images presented by illuminated spaces. The study of the effects of observing different surface brightnesses, of different areas, in various positions, presenting various contrasts in brightness with their surroundings and at different distances from the observer will if consistently planned, furnish the information from which the effects of complex lighting installation, present or future, may be determined (by proper test method). Information founded upon this analysis should as well point the way to different and improved methods of lighting in the future.

As an assistance to the work of representing results on photographic prints, the study of photographic processes with a view to developing a set of specifications as to processes and materials so as to render possible faithful and useful photographs is recommended.

The subjects of so-called "direct" and "indirect" lighting were next discussed and the opinion developed that these terms properly described lighting "units" rather than lighting "systems."

As describing systems, these terms are incomplete and are not based on the significant factors which, as indicated above, are the area and intrinsic brilliancy of the light source, its visibility or concealment, the general direction of the light flux received on the working plane. It developed on discussion that two lighting systems exactly the same as regards directional values, intensity, etc., might in one case be direct and in another case an indirect system. Also cases would arise where direct lighting is accomplished by indirect fixtures, or semi-indirect. In this connection weight must be attached to the fact that popular usage

d understanding of the terms "direct" and "indirect" is at-hed to the fixtures themselves. Weight must also be given the fact that the really significant features, such as softness shadows, concealment of illuminants, etc., which are char-eristic of one so-called "system" may readily be copied by other "system." It, therefore, appears to this Committee in-visable for the Society officially to attach the terms "direct" d "indirect" to systems of illumination, but rather to lend its ight to the application of those terms merely to the units. so doing it should leave the way clear for more thoroughly nsidered terms for describing lighting "systems," if any sim-terms can indeed be found to classify in a significant manner the possible combinations of simple factors.

As a basis for definitions of "direct," "indirect" and "semi-lirect" *lighting units*, the Research Committee suggests the lowing, abstracted from a paper shortly to be published by L. Powell.

> *Direct Unit:* A lighting device from which over half the emitted light flux is directed downward, or to the side, reaching the surface to be illuminated without being reflected by the walls or ceiling.
>
> *Semi-Indirect Unit:* A lighting device employing a diffusing or translucent medium to direct most of the light to the walls or ceiling to be redirected for use, a part of the light being diffused through this medium.
>
> *Indirect Unit:* A lighting device from which all the light emitted is projected to the ceilings or walls and then reflected to the object to be lighted.

It is not expected that these definitions will cover all possible es which may be developed. It must not be forgotten that only complete specification of a lighting unit is by its candle-wer distribution curve, its dimensions, intrinsic brilliancy, etc. ie same unit may be direct or indirect, depending upon iether it is turned up or down, so that these definitions are ictly of the *unit as used*.

A partial bibliography of the subject is appended. The cor-spondence between the various members of the committee and Chairman, containing in greater detail the material of which s report is a summary will also be on file and may be con-lted by interested parties. HERBERT E. IVES, *Chairman.*

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MEMORANDUM.

Dr. C. E. Ferree: I have the following comments to make on the paragraph of the above report entitled "Subjects for Study." (1) In the first sentence we find the statement that "investigations of lighting conditions from the standpoint of physiology and psychology, the study of methods of tests for effects upon the eye, etc., should be made initially upon the simple component factors which in combination produce all the retinal images presented by illuminated spaces." My contention is that in a situation as complex and as new to investigation as is the lighting situation from the standpoint of the eye, it is utterly impossible

know without a great deal of preliminary investigation what component factors are. After two years of such preliminary estigation I can be sure of identifying only a part of these tors. It is utterly impossible that the initial investigation uld have been of the type specified in the report, or that it be continued in this way alone from this point on. (2) e second sentence of this paragraph tells us that "the study of effects of observing different surface brightnesses of differ- areas, in various positions, presenting various contrasts in ghtness with their surroundings, and at different distances m the observer will if consistently planned, furnish the in- mation from which the effects of complex lighting installa- is, present or future, may be determined." According to this ement we have in the study of a lighting situation the varia- is of one factor only, namely, the distribution of surface ghtnesses, to consider. Coming at this time this statement is narrow. (3) It is extremely unsafe to attempt to recon- ict a situation from a study of factors until we are definitely e what all the factors are. We can not assume our factors get them by inspection and be sure of this. A survey of erimental procedure in general shows us that we arrive at a owledge of what these factors are only by means of a great l of preliminary investigation. The history of experimental rk is too full of instances where the study and reconstruction the kind recommended in this report are made upon the is of an incomplete list of factors. (4) My personal experi- e thus far with the problem referred to leads me strongly to eve that the plan of work recommended is incomplete, im- cticable, and very apt to lead to wrong conclusions. We e found it necessary, for example, to make our preliminary rk consist of a variation of concrete conditions in order to ive at some fairly certain knowledge of what the factors are m the standpoint of the eye that one has to deal with in ial lighting. As fast as this knowledge has been gained, we e taken up the study of factors in separation, keeping all the ile in making our variations as closely as possible to con- te lighting conditions. In conformity with this method a con- erable study of factors in separation has already been made.

As I understand the force of the recommendation made in the above report, we should have assumed in the beginning that we knew what the component factors are in lighting, and have passed at once to the kind of study recommended. May I point out in this connection that we are investigating the problem of lighting at present only in relation to the eye's loss of efficiency as the result of a period of work, and that it is only recently that we have had any method at all of testing this point. Without any preliminary testing of concrete lighting situations with reference to this result, it would, I think, have been wholly absurd to have assumed that we knew the factors that cause loss of efficiency. In short, the kind of study recommended in the report, if not too abstractly made, may be included in an investigation after the work has reached a certain point and is being included in our work, but it can not safely be adopted as the initial step.

REPORT OF THE RESEARCH COMMITTEE.

(Meeting held March 14th, 1914.)

Present: Messrs. Bazzoni, Crampton, Ferree, Crittenden, Lancaster, Powell, Langdon, Richtmyer, Dunlap and Ives.

The subject for discussion at this third meeting of the Research Committee was:

TESTS FOR VISUAL EFFICIENCY.

Under this title were included tests for the physical condition of the eye, tests for performance, tests for discomfort and tests for fatigue.

No more important subject for research in illumination now exists than that of determining the effect of various light distributions upon the performance of the visual mechanism. A sensitive and reliable test method should be an invaluable aid in deciding between lighting devices and methods, should warn of conditions ultimately dangerous and should aid in the design of new types of lighting.

The first part of the meeting was largely taken up by an outline demonstration by Dr. Langdon of the various tests regularly made by the ophthalmologist. These are:

(1) An examination of the external muscular and pathological conditions to detect malformation or injury. Rough test of the parallelism of the eyes by watching them follow a moving hand, or by noting the movements of the reflections on the corneas.

(2) Examination of the pupils, their reaction to light, their size, which is different with age, and in myopes and hyperopes.

(3) Tests for convergence.

(4) Tests for visual acuity, measuring by the fraction $\frac{d}{D}$ where D is the distance at which a line of Snellen type should be read, and d the actual reading distance.

(5) Examination of the visual field, for light and color limits, with the perimeter.

(6) Test of "light sense" or threshold of perception. To this is sometimes added threshold of discrimination.

(7) Test of binocular fusion, using the Maddox rod and amblyoscope.

These tests were discussed from the standpoint of detecting the effects of lighting conditions and in this discussion other allied tests were brought forward and considered. In general, any function of the eye which is influenced by lighting conditions offers itself as a test for performance or fatigue. The different possibilities must be judged on the basis of sensibility. On this basis the following test methods were considered.

Visual acuity, or the ability to distinguish detail. This is pretty generally agreed to lack the necessary sensibility for the present purpose. Lighting conditions undoubtedly extremely uncomfortable and fatiguing fail to affect the ability of the eye to pick up detail, due apparently to its capacity to respond well to increased demands. The interesting point was brought out that while ophthalmologists pay little attention to the illumination of their test cards, as long as it appears "sufficient," the photometrist has tried to use the variation of visual acuity with illumination as a means of illumination measurement. The two different points of view emphasize the necessity of the two sciences being brought into better acquaintance. It is suggested that a joint committee of the Illuminating Engineering Society and representative ophthalmological societies should be formed to deal with the question of test card illumination.

Fluctuation of visual acuity.—Under this head comes the test devised by Prof. Ferree in which the ratio of time clear to time blurred of a simple test object is plotted. This test, which is in essence one for the power to sustain clearness of vision, has shown sufficient sensibility to differentiate between types of lighting distributions. A variation of this is proposed in a letter from Mr. J. R. Cravath, consisting in making the illumination fluctuating in order to tire the iris. The results from tests made in this way will be awaited with interest. The prevalent opinion in the committee was, however, that since variations in the size of the pupil have little effect on clearness of vision, the seat of the fatigue must be located elsewhere than in the iris.

Brightness and color discrimination thresholds.—The ability to distinguish differences of brightness and color appears to fall under the condemnation of lack of sensibility.

Perception of flicker.—The speed at which a black and white sector disk must be run in order to make flicker just disappear is a function of the illumination which is very sensitive to conditions of pre-exposure, pupilary aperture, etc. It suggests itself in this connection. Data as to sensibility to change in the surrounding visual field or to fatigue appear to be lacking.

Reaction time.—Allied to the last test is one now being studied by Prof. C. C. Trowbridge. One half of the photometric field is changing in brightness at a known rate. The instant at which it appears to match the fixed field is recorded. This instant is different from the true instant of equality, and the amount of this difference is a function of the observer's retinal and other conditions.

The adaptation curve.—In making tests of the threshold of light perception, sensibility is increased by previous adaptation in a dark room. Behr has found that the curve showing the reciprocal of least perceptible light against time is greatly altered by certain bad lighting conditions. Further study of this effect is desirable.

Light and color fields.—The light and color fields, as determined by the perimeter have been believed to be intrinsically different in extent, and different in health and disease. Doubt has been thrown on this statement by experiments on colors of different luminosity. The standardization of perimeter test spots and illumination is a worthy subject for joint committee action.

Fixation and binocular fusion.—Both these are capable of fairly definite and delicate test, but published details of sensibility or of trial in connection with lighting conditions are meager.

Winking.—Recklinghausen has used the rate of winking as a measure of ocular fatigue, finding different rates with different colors of light.

Probably the most striking feature of these possible test methods is the difficulty of obtaining any data of their relative sensibility for the present purpose. Were there any simple test which could be agreed upon and to which they could all be sub-

jected the situation might be greatly improved. The following is suggested:

Let the work to be done by the eye consist in reading print of the type used in the *Bulletin* of the Bureau of Standards, printed upon similar paper, of the same size as that. Let this be under an illumination of 25 meter-candles, supplied by a light source behind the worker. At 45° from the center of the printed page hang a 25-watt, clear bulb, tungsten lamp, both printed page and lamp being against a black background. The sensibility of the test method might then be shown by its decision on the condition of the eye after reading for a certain time, with and without the disturbing light at the side. In tests of fixation, winking, etc., the test object could take the place of the printed page and, if possible, be made of the same brightness. The rate of winking, etc., with and without the side light should be compared.

Future work in this important field must initially to a large extent be concerned with the development and comparison of test methods (including the ones above listed) which will indicate differences of efficiency under such primitive conditions as just outlined.

A partial bibliography of the subject is appended. The correspondence between the various members of the committee and the chairman, containing in greater detail the material of which this report is a summary will also be on file and may be consulted by interested parties.

HERBERT E. IVES, *Chairman.*

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REPORT OF THE RESEARCH COMMITTEE.

(Meeting held April 18th, 1914.)

Present: Messrs. Crampton, Crittenden, Ferree, Langdon, Bazzoni, Powell, Dunlap and Ives.

The subject for discussion at this fourth meeting of the Research Committee was:

PHOTOMETRY, APART FROM COLORED LIGHT PHOTOMETRY.

The meeting opened with an attempt to clarify the statement of the chief problem of accurate light measurement. Much confusion has been caused in the past by lack of clear separation between methods of accurate measurement and tests of what the illumination enables one to do. Primarily, of course, one desires an illumination which will permit certain activities to be carried on, such as reading, drafting, distinguishing obstacles, etc. The first idea of an illumination test is a direct test of ability to read, draw, etc. Now, while the test of illumination should give this information, experience shows that all direct tests of this sort suffer under the disadvantage of very low sensibility. The results depend largely upon the condition of the observer. As a consequence the approved practise is now to record the results of the fundamental tests on visual acuity, etc., by accurate and reproducible physical methods, making the experiments with many observers, over extended periods of time. It would be impractical to measure lighting installations by visual acuity, or other similar tests, for the reasons stated, but the criteria once established and recorded by exact physical methods, the desired conditions may be easily reproduced. The practical problem of photometry, therefore, becomes one of means to determine and reproduce exact physical conditions previously determined as satisfactory by performance tests.

Of physical instruments for this purpose, by far the most sensitive as yet used is the human eye, operated as a null instrument. That is, it is used to determine a condition of equality of illumination, for which it is very sensitive, and by the application of certain mechanical aids, such as the inverse square law, sector disks, absorbing screens, the relative intensity of the illumina-

ion-producing light source or the brightness of the observed sur-
ace is obtained.

By what means can the eye be made more sensitive to slight lifferences between the adjacent parts of a photometric field? Probably the most definite advance on this line was the introluction of the contrast principle by Lummer and Brodhun, vhereby the judgment is not made of equality of brightness, but of equality of slight differences in brightness. An interesting uestion in regard to this type of field is whether the sensibility nay be increased by a change in the size of the contrast spots. The smaller these are the greater the induced brightness differnce.

Considerable time was devoted to the question of binocular vs. nonocular instruments. Experiments have been published howing a marked increase of sensibility by the use of two eyes. Most of the commercial photometers are used with both eyes, lthough the more sensitive precision instruments are monocular. nteresting experiments here are on the effect of closing or eaving open the unused eye, the angular extent of the field, and he brightness of the field of view of the unused eye if open.

An important field of study is on the influence of the brightess of the photometric field, of the surroundings of the photonetric field and of the photometer room. On the one extreme is he bright photometer field with black surroundings, in a blackvalled room; on the other extreme a low brightness field with right surroundings in a light room. Is the first extreme the ondition of greatest sensibility, or does it lie at some intermedite point? Certain experiments indicate greater comfort and ess variation between settings with the photometric field surounded by a large field of the same area of brightness. Further vork is desirable.

The next point to consider, having the null instrument of desired sensibility, is means for altering the illumination of the hotometric field to produce the condition of equality. The most ommonly used means is the variation of distance, utilizing the nverse square law. This pre-supposes a point source of light. One of the most important recent aids to photometry is the development of point source lights, by means of which an enor-

mous variation in illumination may be produced without danger from deviation from the inverse square law.

Other means discussed were sector disks, of fixed and variable opening, neutral tint screens, fixed and variable, "paddle wheels," etc. The mechanical and other limitations to perfection in these instruments were discussed. Each has its field, although no one is flexible enough for all needs.

The discussion of distribution and integrating photometers appeared to indicate that this branch does not offer any important problem for research in so far as visual photometry is concerned.

The final subject considered by the Committee was "physical photometers". The search for a "moving pointer" to indicate intensity of illumination is as old as photometry, and owes its existence to the universal desire to reduce all measurements to indications by a positional rather than a quality criterion. A physical photometer possessing greater sensibility than the eye for detecting small differences would have valuable uses, such as in the intercomparison of photometric standards. One which had permanence of calibration and a simple relationship between illumination and response would offer great advantages from the standpoint of convenience, since no comparison lamp would be needed. Recording and time-integrating physical photometers also figure among the desirable possibilities.

The various physical photometers which have been proposed were discussed in view of these criteria, as follows:

Photography possesses the disadvantage of no greater sensibility than the eye; of not having a strictly linear light-density relationship and of requiring auxiliary measuring apparatus for determining the density of plates. It does offer possibilities in the matter of integration or fluctuating illuminations, such as arc lamps, which may outweigh the disadvantages mentioned.

Radiometers, such as the thermocouple, bolometer, etc., measure the total energy, visible and invisible. Hence unless means are taken to eliminate the greater part of the invisible energy, results in conflict with visual results are possible. If the invisible energy is obstructed the sensibility of these instruments is low.

Selenium has achieved considerable notoriety as an aid to

photometry. It possesses great sensibility, but the latest researches show such a complicated method of response to light that it is opposite of promising in this connection.

The photo-electric cell is perhaps the most sensitive of all physical photometers and has been used in such delicate work as stellar photometry. Recent work has cast doubt on the uniformity of the illumination-current relationship in different cells, so that work still remains to be done before this means may be recommended.

A partial bibliography of the subject is appended.

The correspondence between the various members of the committee and the chairman, containing in greater detail the material of which this report is a summary, is on file and may be consulted by interested parties.

HERBERT E. IVES, *Chairman.*

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RED AS A DANGER INDICATION.*

BY WILLIAM CHURCHILL.

Synopsis: The increasing use of red as a danger indication raises the question whether such signals are effective for the color blind. Railroad signal practise has developed six standard colors: red, yellow, green, blue, purple, and lunar white. These are all available for normal vision, although varying in distinctness and effective range. In establishing warning indications for the general public, it is important to determine exactly what the effect of the respective colors is to color blind vision, and investigation of this problem should be undertaken. At the same time a colored danger symbol should be developed and standardized.

Red is the accepted sign and symbol of danger. The full explanation of this significance probably lies hidden in the long unknown past out of which our race has evolved. Some psychologist could weave quite an interesting narrative by tracing back toward the origins of our consciousness the story of the unique importance of red as the color of warning. Red is preëminently the color which, throughout nature, attracts attention, excites curiosity and arouses to action. Nature does not make lavish use of the bright reds and scarlets in laying out her color scheme, but when she does employ those hues it is generally to bring about definite action. Red is the antithesis of protective coloration; it is the aggressive color and always catches the eye. Red petals and red plumage, as we all know, play an important part in the story of plant and bird life.

Red is always mentioned along with green and blue, or with yellow added to the list, as one of the "cardinal colors." There is a plausible suggestion that the psychological emphasis of these three or four colors is the result of evolution in a world where the fundamental color distinctions are the blue tint of the sky, the green hue of vegetation, the yellow of the sun and fire, and the deep red of blood. In this connection it is of some interest to note that according to philology a definite term for red is found earlier than one for blue in the development of a language. At

* A paper read at a meeting of the New York Section of the Illuminating Engineering Society, April 9, 1914.

one time a theory was advanced[1] that the Greeks of Homer's age were probably without a sense for blue, since the expressions applied to the blue of the sky are used equally for any dark or gray object.

Without dwelling further on these speculations, it is quite sufficient for our present purpose to realize that red has been from time immemorial the color of attention and action. Most naturally, therefore, when it became necessary in the development of railroad service to select a symbol of danger, red was the color chosen. In the course of time, green was adopted either for a clear or for a cautionary indication, and within the past twenty-five years yellow, blue, purple, and lunar white have been added to the list of recognized signal colors. In semaphore signals, European practise is confined mainly to the use of red and green. Here in America, where automatic signalling is far more extensively developed than abroad, the general practise ten years ago was red for stop, green for caution, white for clear. Of recent years most roads have adopted yellow in place of green for caution and made green the clear indication.

Railroad service necessarily requires a variety of signal indications. There must be "classification signals" on the engine to indicate the class to which the train belongs (regular, special, or first or second section), marker lamps or flags at the rear, switch indications, semaphore signals for automatic, interlocking, or manually operated signals, secondary indications known frequently as "dwarf signals," colored lanterns and flags for use by flagmen and switchmen, and colored fusees for additional rear end protection under special conditions.

By day, "position" signals, that is to say indications given by the position of a moving blade, or form signals, given by the shape of targets, are utilized to a large extent. By night, however, American practise depends wholly on colored light indications. In Europe some use is made of position signals on switches at night by illuminating white glass screens visible through metal openings of different patterns. Such lamps are, however, extremely cumbersome and effective only at very short range owing to limitations in the size of the lamp.

Whatever the system of signal indications, it is obvious that

[1] Geiger, *Zur Entwicklungsgeschichte der Menscheit*, 1871.

there is no place in active railroad service for any man with defective color sense or even with impaired vision, unless full correction can be made with suitable glasses. Rigorous tests should, of course, be made at stated intervals of the eyesight of all employees engaged in train operation or maintenance of way. This is fortunately the rule on most railroads at the present time. The utmost pains should be exercised to prevent young men with any defect of sight or hearing from joining the service. It is far easier and more charitable to exclude such men at the start than to eliminate them after they have once gotten in the ranks. Every railroad man knows the meaning of this statement.

Similar remarks apply to the marine service, but at sea the established system of signal lights makes less demand on the color sense than is the case in railroad service. The only colored signals used are red and green side lights, red flashes or fixed red lights from light houses and occasionally colored rockets or flags. Buoys are painted white, black, or red.

The past ten years has witnessed a great increase in the use of red lights by night and red signs by day for a variety of warning indications entirely outside the railroad and marine service. Custom long ago fixed on the red lantern as the proper warning indication at an open ditch or other obstruction in a highway or public street. This practise probably grew out of the use of red in railroading. When automobiles began to multiply, it was quite natural that, along with headlights and sidelights, the red tail-light should make its appearance and soon be made obligatory by law. More recently still, public demand for better fire protection in hotels, theaters and public halls has given rise to the habit of marking all exits by red lights; and now the movement for "Safety First," spreading from the railroads to industrial plants, has led to the wide spread introduction of red signs or lights not merely for exits, but also to indicate dangerous parts of machinery, dangerous localities, high power transmission lines and the like. In New York State and possibly some others, the law prohibits the use of red lights in factory buildings except as marking exits but red signs for various warning purposes are quite common.

This rapid increase in the general use of red as a cautionary indication obviously gives rise to the question as to what we are going to do to protect the color-blind individual for whom the red signs and red lights may be ineffective. According to the usually accepted statistics about four per cent. of all males and one per cent. of all females are more or less color-blind and in the great majority of cases red, or red and green, are the colors affected. Ought not a careful investigation be made to determine whether the ordinary red light or red sign is recognized as a danger signal by those afflicted with red-blindness? If not, can some special provision be made to cover all such cases as well as adapted to individuals with normal eyesight? With this thought in mind, a suggestion has recently been brought forward to adopt some other color or colors than red, *e.g.*, a combination of yellow and blue, as a warning sign in industrial plants. The topic is surely a pertinent one, deserving of careful consideration, and should not be answered without much definite evidence, which seems to be lacking at present.

Not long ago, a letter was written by a prominent automobile club official seriously making the suggestion that laws be enacted giving automobiles the sole right to use red tail lights. He thought the railroads could easily find some other color which would answer their purpose just as well and confusion would thereby be avoided! Is it not time to investigate carefully any possible limitations to the proper use of red as a danger indication? As a preliminary to such discussion possibly some remarks based on the writer's experience in developing and testing colors for railroad signal service may be of interest. The statements made are based on the use of colored glass. Pigments and dyes are not taken under consideration for the simple reason that our experience has not covered that field to any extent.

RAILROAD SIGNAL COLORS.

It is estimated that the solar spectrum includes about 150 hues perceptibly different to the average eye with approximately 30 hues of purple lying between the two extremes of the visible spectrum. For signalling purposes it is obvious that a color should be as far removed from white or so-called "white lights"

as possible, in other words should have the highest possible degree of "saturation," or "purity" as it is frequently called, and should have the highest photometric intensity compatible with a proper degree of saturation. Furthermore the colors selected must be sufficiently unlike in hue to leave little or no chance of possible confusion.

The Railway Signal Association specification, which was adopted in 1908 and represents laboratory investigation as well as service tests under all sorts of conditions extending over a period of more than five years, recognizes six signal colors: red, yellow, green, blue, purple, and "lunar white." Of this list blue is the least satisfactory for reasons to be mentioned later, and is no longer used except in special instances.

The effective range of these colors under average weather conditions when used with the customary semaphore lamp and lens is approximately as follows:

Color	Effective range	Approximate transmission coefficient for standard semaphore lamp (oil burner)
Red	3 to 3½ miles	0.20
Yellow	1 to 1½ miles	0.35
Green	2½ to 3 miles	0.17
Blue	½ to ¾ mile	0.03
Purple	½ to ¾ mile	0.03
Lunar white	2 to 2½ miles	0.15

In this connection it may be of interest to note that all the evidence accumulated respecting the range of lights in the respective signal colors indicates that the minimum intensity which can just be perceived—the vanishing point of sensation—is very much lower than the figures customarily given. For example, there is no doubt but that a distinct perception of red is possible with an intensity of only 5×10^{-7} meter-candles.

In actual service it is seldom necessary to see a signal more than 3,000 feet (914.40 m.), but a light of barely sufficient intensity to be visible that distance would never be feasible for an important indication. Volume of light is essential as well as correct hue, and it does not require very dense fog or smoke to cut the range of even a standard red signal down from three miles (4.82 km.) to a few hundred feet.

Time does not permit the writer to take up in detail the theory

of color as it affects the selection of these six standard colors, nor to discuss the methods followed in laboratory study of the problem. Suffice to say that by repeated melts of all available glasses, spectroscopic analysis, photometric and service tests, the theoretical possibilities were narrowed down to six definite tints. Numerous service tests were absolutely essential since atmospheric absorption and reflection, which cannot be effectively simulated in a laboratory, produce certain definite changes in the appearance of all signal lights. All colors seen at a distance are shifted more or less in hue toward the red end of the spectrum. This effect is, of course, most apparent in fog, haze or smoke; at times it is strong enough to make a dull green out of a blue light, a yellow out of a "white" light, a red out of a yellow light.

A few remarks on each of the recognized signal colors may help to bring out some points of general interest.

RED.

To normal vision red is beyond all question the most effective color for a danger signal. It is quite true, of course, that the eye is far more sensitive to light in the middle of the spectrum than toward either extreme, but of much greater importance is the fact that as the apparent size of the source diminishes red never ceases to look red. Its chromatic and achromatic threshold are always the same. This is not strictly true of any other color although a good signal green approaches close to such a requirement. This fact which has been recognized in practise ever since railroads began to use red lights in signalling is corroborated by numerous experimental researches of recent years.[2]

Red has the further advantage that the intensity of the light can be increased by the addition of a considerable proportion of reddish orange light (620-590$\mu\mu$) without a pronounced change of hue because the eye is not very sensitive to change of wavelength in that region. On this account red has the longest range of all signal colors. That advantage coupled with the fact that so long as it is visible at all, regardless of distance, intensity or atmosphere, a red light is always and unmistakably *red* makes it the ideal color for a danger indication when color blindness can be disregarded.

[2] Wundt, *Physiologische Psychologie*. 5th Ed., Vol. II, p. 176.

YELLOW.

Yellow at best is not an ideal signal color. Its chromatic threshold is much higher than its achromatic threshold; or in other words, it can be seen as a light of indistinct color much further than it can be definitely recognized. This difficulty is of course greatly increased by the circumstance that most of the ordinary sources of illumination are more or less yellowish in predominant hue and hence liable to cause confusion. The yellow signal may be mistaken for a "neighborhood light" close to the right of way. Some reaction time experiments conducted by the author twelve years ago demonstrated quite conclusively that yellow required a longer time for recognition than red or green and that yellow and white were frequently mistaken for each other.[3]

The fact that atmospheric absorption may make a yellow signal appear reddish at times is unfortunate but never a serious objection so long as red remains the danger indication. Experience on many railroads has proven during recent years that the red-yellow-green combination is distinctly preferable to the older combination—red-green-"white" provided standard colors are used throughout.

GREEN.

Green is the most effective signal color except red. It is usually somewhat below red in range, due in part to atmospheric absorption, but a bluish green (approximately 500 $\mu\mu$.) gives very good results. Recently it has been found possible to increase the transmission of such a glass by 35 per cent. over the present standard without any loss in distinctness of hue, and it is probable that this new modification will show results in range of visibility nearly equal to the present standard red.

Since red, yellow and green are the three principal long range semaphore signal colors, it is important that all should have approximately the same intensity, so that no one color may overpower either of the others when displayed in more or less close proximity to it. But the sources of illumination generally used (oil or incandescent lamps) are far stronger in yellow light than in either red or green. This means accordingly that the trans-

[3] Churchill, "The Roundel Problem," *Proc.*, Railway Signal Association, Oct., 1905.

mission of the red and green glasses should be kept at a maximum, while the yellow can properly be somewhat reduced below the highest intensity possible to obtain.

BLUE.

Blue and purple are short range indications because the proportion of blue and deep red contained in the light of the sources commonly employed is extremely small. Both these colors must, of necessity, transmit quite a proportion of bluish green light in order to secure even a moderate amount of percentage transmission and range. Blue light is so rapidly lost by atmospheric absorption and reflection that the color of the blue signal tends to become distinctly greenish with distance. On that account blue never gives a really effective indication and is now seldom used having been largely supplanted by purple.

PURPLE.

In a standard purple signal glass, the proportion of bluish green light transmitted is offset by red from the extreme end of the spectrum. The result is a color verging on magenta and about equally distant on the color scale from both standard red and standard green. The chromatic aberration of the eye is strikingly apparent in viewing a purple lens at a distance of 100 feet (30.48 m.) or more. The light appears ordinarily as a purple spot with a halo of deep bluish light surrounding it. This effect is varied more or less by conditions of astigmatism as is well known to ophthalmologists. Such a purple produces a signal indication which for distinctness compares rather favorably with the other colors. Unfortunately its use is restricted by the fact before mentioned that its total transmission and range of visibility is low.

LUNAR WHITE.

While studying the problem of how to render the yellow signal more effective the writer was led to the conclusion that a bluish white signal could be made useful as an additional indication and would in some respects be preferable to yellow. By means of a pale blue glass we are able to eliminate enough of the yellow in a kerosene flame or incandescent lamp to make the

light appear almost white with a slight preponderance of blue. This new possibility was called "Lunar White," and has come into use as a clear indication for switches on a number of roads. In actual service it has proven to be at least as distinctive a color as yellow and to possess longer chromatic range for most observers.

RED SIGNALS AND COLOR BLINDNESS.

The established system of railroad signal colors briefly mentioned above is based on the assumption of normal color vision. But when red is used as a warning signal for the general public, the question naturally arises whether red-blind individuals are properly protected. It is reasonable to assume that about 4 per cent. of all the drivers of automobiles and other vehicles are color-blind. Before the importance of eliminating color-blind men from railroad service was appreciated, it was morally certain that at times serious wrecks were caused by defective color sense. It is highly probable that at the present time some automobile accidents are due to the same cause, although definite evidence is very difficult to obtain. It is hardly to be expected that all automobile drivers could be compelled to pass a test for color vision. Neither is it fair to ignore the color-blind in establishing a standard warning indication for vehicle tail lights, highway obstructions, fire escapes and similar purposes.

Should not a serious effort be made to determine by actual tests with a large number of color-blind subjects whether the present red signals furnish sufficient protection? It is reasonable to assume from what is known regarding the peculiarities of abnormal color vision that a red-blind individual will perceive the average red light as a yellow of some sort, and that the yellow in such case will be of low intensity. As the color exhibited tends toward orange, the hue is likely to become more distinct and the intensity, of course, higher. A purple light probably appears blue to the red-blind subject, and is at times confused with green lights on that account. This is one of the frequent mistakes made by color-blind persons undergoing test. But either an orange-red or a purple light presumably is much easier for the red-blind or red-green-blind to recognize than an ordinary red light. It would be a waste of time to speculate on this

point, but a carefully conducted series of tests would soon bring some definite evidence to light.

If either a reddish orange or a purple proves to be distinctly better for abnormal color sense, a standard shade could easily be determined which would be entirely satisfactory for normal color vision. Incidentally there might be some advantage in utilizing a hue which would be somewhat different from the standard red of railway service. It is the constant effort in signalling practise to reduce the number of red lights visible along the right of way to a minimum, so that red may indicate only two possible conditions to the engineer's eye: a "high-signal" set at danger or a "tail light" at the rear of a train.

Parallel to the investigation respecting the perception of red lights by the color-blind, a study should be made of the best pigment color or colors to use for danger indications. It would seem desirable, in this connection, that a standard danger symbol be developed and made international, just as in the marine service all over the world green signifies a starboard light and red a port light. Such a symbol should be simple but as distinctive as a red cross flag. Theoretically, a circular blue or orange band enclosing a red center would seem to fulfill all requrements. It would be more striking in appearance than any mere black and white sign and it would furnish a colored indication to all types of color vision except the very rare cases of total color blindness. Practically no instances are found where the color sense for both red and yellow or red and blue is lacking in the same subject.

Such a symbol and such standardization of practise concerning lights for danger indications in public places or industrial plants might render some real service in the cause of "Safety First" and would certainly eliminate one possible cause of unnecessary accidents.

DISCUSSION.

Mr. C. K. Freeman (Communicated): I am glad to hear Dr. Churchill say that a red light "is always and unmistakably red regardless of distance, intensity or atmosphere". Since the advent of yellow light as a cautionary indication in railway operation, there has been, at times, some question in the minds of

railway officers as to the possible mistaking of "red" for "yellow." From numerous observations witnessed under actual working railroad conditions, in clear, rain and foggy weather there seems little, or no foundation for this fear. Some recent experiments were made with two signal lamps, located seven feet apart, displaying simultaneously red and yellow respectively during both fog and clear atmosphere. It may be of interest to note that during the foggy state, both red and yellow were correctly observed at a distance of 1703 feet (519.07 m.) by three practical railroad men. Beyond this distance the yellow could not be determined by the naked eye.

It should be further stated that the red lens referred to was a sector of spheroidal lens and of color shade very much higher in transmission than the usual reds now found in railway signal lamps.

Both lamps were equipped with kerosene oil burners taking the ordinary 5/8-inch (1.58 cm.) flat wick, the flames being adjusted to approximately same candle-power by the photometer.

A FUNDAMENTAL PRINCIPLE OF ILLUMINATION.*

BY HERBERT E. IVES.

Synopsis: This paper points out that the light source is always of higher intrinsic brilliancy than the object it illuminates. If it be accepted that the object of interest should be the brightest in the field of view, it follows as a necessary consequency that the light source must be concealed. It is suggested that the visibility or concealment of the light source gives one element of a rational classification of lighting systems.

It is probably pretty widely agreed that the object which it is desired to see should be the brightest thing in the field of vision, whether it is the page of a book, the face of one's vis-a-vis or the piece of work on a machine. This statement is based upon our knowledge that the eye is attracted toward the brightest spot within the visual field and upon the well known fact that pupillary adjustment is for the brightest object seen. While objects somewhat less bright than the brightest point may be observed without discomfort, despite this pull upon the eyes, the brightness ratio need only be a matter of a few times in order to make seeing difficult. Dark furniture, clothing or shadows become hard to see unless the brightest objects are exluded. And, of course, everyone knows that nothing is a better preventer of seeing than a bright light adjacent to the relatively much darker object one tries to observe.

While these facts are well known, a principle which clearly follows from them has not been generally emphasized. The principle is this: *The light source illuminating an object under observation must be concealed, no matter what its intrinsic brilliancy.*

This statement lends itself to very simple proof. Consider the light source of lowest possible intrinsic brilliancy which can give a certain chosen illumination. It consists of an infinite plane, such as a uniformly cloudy sky. Take a perfectly white matt reflector and place it parallel to the infinite plane at any

* A paper read at a meeting of the Philadelphia Section of the Illuminating Engineering Society, April 17, 1914.

distance from it. What is its intrinsic brightness? The same as that of the plane. Take any other reflecting surfaces, such as those found on ordinary everyday objects; these will all be of lower reflecting power than the one just considered and will, consequently, be less bright than the light source. Since all other light sources giving the same illumination will be brighter than this infinite plane it follows at once that in order for any illuminated object to be less bright than the light source the latter must be concealed.

Now a word must be said about this concealment of the light source. By this is not meant merely the concealment of the original light-emitting unit, such as the mantle or the filament, but the concealment of that surface which really acts as the light source of the point or plane of interest. Thus the bright ceiling used with an indirect fixture is the true light source. It is the true light source, since by no entirely photometric device or measurement can any distinction be made between a diffusely reflecting ceiling, a diffusely transmitting ceiling, or an incandescent glowing ceiling—surface brightness, directional value, shadows, everything is the same. A bright ceiling is, in short, just as much a light source to be concealed as is a filament, although to be sure the discomfort from looking at a bright ceiling is far less than that in looking at a filament. Although the ceiling has great advantage from the standpoint of soft shadows, it is *always* brighter than the object it illuminates. Further, by concealment is not necessarily meant complete concealment, but only such a degree of obscuring as will decrease the brightness of the lighting unit, as seen, to a point below that of the objects it illuminates. That is, the illuminant need not necessarily be furnished with an opaque metal "behive" reflector; the reflector may be translucent, but of a very low transmission.

It is a matter of some interest to study a nnmber of cases of satisfactory lighting, both natural and artificial, from the standpoint of this criterion of concealment. Outdoor daylight is least satisfactory when the sky is uniformly overcast; most satisfactory when the sky is blue and the ground is illuminated by the sun. In the latter case the sun itself becomes a concealed light source, since we never really look at it. In the former case we

find relief from the glare of the sky by wearing a hat and glancing downward, or by travelling in a depression such as that furnished by the buildings of a street or the trees of a park. An open plain under an overcast sky is the nearest practical approach to the infinite plane illumination considered above as giving the lower extreme of brightness in an illuminant, but this is not satisfactory unless one looks down. Of course other considerations at times enter into daylight, such as the absolute value of the brightness—a white pavement may be unbearably bright, but this is quite aside from the present argument.

Indoor daylight is, when satisfactory, a typical case of concealed lighting. For here the sky is the light source which illuminates the floor and working planes of the room. If it is not visible by the occupants, this condition is one of the best to be met with. If the shades are raised too high, or if a blank sky faces instead of the usual dull building or foliage, then the light source becomes visible and a disagreeable condition is met.

Store window lighting furnishes another notable example. If the light sources are visible the goods are obscured; if the light sources are concealed in deep reflectors, or behind a screen at the front of the window, then probably, judging by the present criterion, the best possible illumination conditions are realized. In this connection may be noted the displaying of table lamps, floor standards or other lighting fixtures in store windows furnished as rooms. Many of these look exceedingly well, as long as the actual illumination of the imitation room is furnished by concealed lights. But use the same fixtures for the illumination of a real room and the effect is fundamentally different. The art glass, cretonne and silks which in the store windows are objects of interest, being of only slightly higher intrinsic brilliancy than the illuminated objects (with which we are not trying to work) become in the home the bright light sources with which we try to illuminate our working planes, usually clearly visible and in sharp contrast to unilluminated backgrounds. In the store window they frequently meet the condition of being less bright than the table top, blotters, books or other working planes, but totally fail to meet that condition when actually used.

The old much-lauded student lamp is another excellent illus-

tration of concealing the light source. The size of the unit and its construction are such that the reader can hardly fail to have his book page the brightest object visible; the only possible brighter objects are the flame and the lamp shade—the former is concealed, the latter is always of considerable opacity.

The recognition of the significence of concealment of the light source makes possible a more fundamental basis for classifying lighting installations than do the terms now in common use. For instance, the term "direct" applied to a unit is commonly understood to mean that the larger part of the emitted flux of the illuminant goes directly to the working plane, usually below it. But the character of the lighting from such a unit is totally different when the illuminant is concealed from view and when it is visible. The difference in character produced by concealment or visibility is of overwhelmingly greater meaning than the acceptance of this principle is that a satisfactory lighting unit "direct" or "indirect" characteristics. The typical "indirect" lighting scheme, with its bright ceiling, may be a concealed or visible lighting installation, depending on the height of the room and depending also on whether the worker looks down on his work or straight ahead. Any exposed lighting system may be transformed into a concealed one by merely donning an eye shade.

One immediate practical conclusion that follows from the can never be produced by mere enlargement in area of the light source and the accompanying decrease of intrinsic brilliancy, unless, at the same time, the unit is out of the worker's field of vision. This conclusion applies (for instance) equally to a bright ceiling as the only light source of a room, to a completely enclosing ball of uniformly diffusing material, or to a suspended luminous bowl. These light sources are satisfactory only if the occupant of the room does not see them as he works, or if they are supplemented by such local concealed lights as desk lamps, table lamps or floor standards.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 4, 1914

PART II

Miscellaneous Notes

Council Notes.

A regular meeting of the Council was held in the general offices of the Society, 29 West 39th Street, New York, N. Y., April 9. Those present were: C. O. Bond, president; Joseph D. Israel, general secretary; V. R. Lansingh, C. A. Littlefield, L. B. Marks, Preston S. Millar, Alten S. Miller, J. Arnold Norcross, C. J. Russell, F. J. Rutledge, G. H. Stickney, and Mr. M. Luckiesh, chairman of the Committee on Glare, upon invitation.

The meeting was called to order at 2.20 P. M.

The minutes of the March meeting were adopted as printed.

In accordance with recommendations contained in a report from the Finance Committee, it was voted (1) to deposit the interest derived from bonds and the bank balance of the Society in a savings bank until a reserve of $5,000 is accumulated; (2) to pay vouchers numbers 1657 to 1689, inclusive, aggregating $695.15. The report also suggested that the number of sustaining members be increased.

A report from the general secretary showed that the membership totaled at the present time 1,457 members and 32 sustaining members.

Three resignations were accepted.

Mr. V. R. Lansingh, chairman of the Sustaining Membership Committee, reported informally upon a probable increase in new sustaining members before the close of the present fiscal year.

A written report outlining the activities of the Papers Committee was received from Mr. G. H. Stickney, chairman. It contained a tentative list of papers to be presented at the forthcoming Convention in Cleveland.

A detailed written report from Mr. W. J. Serrill, chairman of the Committee on Reciprocal Relations, was read by Mr. Israel. The Council expressed its appreciation of the activities of the committee.

Mr. Israel, chairman of the Section Development Committee, reported verbally on the work of his committee. Mr. Israel recommended that the matter of joint meetings of sections with other societies be left to the Section Board of Managers. He stated that however desirable these meetings may be, care should be exercised that an excessive number during a fiscal year be not held, in order that the identity of the Society may not be lost. An expression of thanks to the chairman of this committee was voted.

Mr. M. Luckiesh made a verbal report of the work of the Committee on Glare. He told of the influence they had exerted with large and small journals in eliminating glazed papers, and of their efforts at the present time to get in touch with the publishers of school books.

The appointment of Mr. Clarence E. Clewell as chairman of the Committee on Popular Lectures was confirmed.

Mr. Clewell submitted a communication outlining a proposed procedure of the committee.

Reports on section activities were received from Mr. G. H. Stickney, vice-president of the New York Section; Mr. W. J. Serrill, vice-president of the Philadelphia Section; Mr. Ward Harrison, vice-president of the Pittsburgh Section; and Mr. J. W. Cowles, vice-president of the New England Section.

The resignation of Prof. Morgan

Brooks from the Committee on Education was accepted.

The resignation of Mr. R. E. Campbell as chairman of the Advertising Committee was accepted. Mr. F. J. Rutledge was appointed to succeed Mr. Campbell.

Mr. V. R. Lansingh was appointed a delegate of the Society to the United States National Committee of the International Commission on Illumination to succeed Mr. L. B. Marks. The three representatives of the Society on the committee were Dr. Louis Bell, Mr. V. R. Lansingh, and Mr. Preston S. Millar.

The Council outlined the duties of the representatives of this committee as follows:

The exact functions of the representatives from the I. E. S. to the United States National Committee of the International Commission on Illumination cannot be made definite until the purposes and methods of the I. C. I. are fixed.

It shall be the duty of such representatives, however, to enter as fully as may be into the counsels of such National Committee (of which they form a part) to the end that it shall make a dignified and creditable presentation at the meetings of the I. C. I. For this purpose such representatives shall keep the National Committee informed of all papers and reports presented to the I. E. S. which may be pertinent to the objects of such National Committee, or which are covered in the titles enumerated in the letter from Dr. Sharp to this Society dated March 19, 1914. But no action taken by said National Committee which would lead to obligation on the part of the I. E. S. shall be held of binding on this Society without prior consent of the Council.

It was understood that the three representatives as a body are expected to report to the I. E. S. from time to time upon the policies of the I. C. I.

President Bond appointed a committee consisting of Dr. Herbert E. Ives, Mr. Clarence L. Law, and Mr. Thomas Scofield, with Mr. L. B. Marks as an advisory member, to consider the remodelling of the lighting installation of the general offices, and report to the Council.

The question of preparing a handbook on illumination was laid upon the table.

The following by-law was adopted upon a second reading:

All representatives or delegates to conventions or similar bodies, when appointed by the President and approved by the Council, shall be considered as automatically holding office until their work on such conventions shall have ceased, unless the next President, subject to the approval of the Council, shall make other appointments. Such representatives or delegates may be at any time replaced by other representatives or delegates on appointment by the President and approval by the Council. All actions by such representatives or delegates must first be approved by the Council before becoming binding on the Society. This by-law however does not apply to representatives or delegates to other societies or bodies, the work of which by its nature continues indefinitely.

A regular meeting of the Council was held in the general offices of the Society, 29 West 39th Street, New York, May 14. Those present were: C. O. Bond, president; Joseph D. Israel, general secretary; C. A. Littlefield, L. B. Marks, treasurer; Preston S. Millar, J. Arnold Norcross, C. J. Russell, G. H. Stickney, and Prof. C. E. Clewell, chairman of the Popular Lectures Committee, upon invitation.

The minutes of the April meeting were amended slightly and adopted.

Upon recommendation of the Finance Committee it was voted: (1) to authorize the payment of vouchers No. 1690 to No. 1731 inclusive, aggregating $1,888.85; (2) to grant two appropriations amounting to $16.00 to cover a deficit in the expenses of the Lighting Exhibit Committee.

Mr. Joseph D. Israel, general secretary, reported a net increase in membership since the beginning of the present fiscal year of 75 members, making

present membership 1,458, exclusive 33 sustaining members.

;ight applicants for individual memship and one for sustaining memberp were elected. Their names appear :where in this issue.

;even resignations were accepted.

'he decease of Francis R. Frost, :trical engineer, Atchison, Topeka & ıta Fe Railway, Topeka, Kan., was orded.

Ar. G. H. Stickney, chairman of the pers Committee, presented a written ort on the progress of the work of committee. Included in the report s a list of about 41 titles of papers ich have been either promised or gested for the 1914 convention of Society.

'rof. C. E. Clewell, chairman of the pular Lectures Committee, submitted written report on the plans which 'e been outlined for his committee l sub-committees.

\ written report on a meeting of the hting Legislation Committee was d by Mr. L. B. Marks, chairman. on the request of Mr. Marks for tructions as to the work to be pur-d by his committee, it was

Resolved, that it is the sense of the uncil that the Committee on Lighting gislation should undertake to have npiled the state laws and regulations 'taining to natural and artificial light-, which are now on the statute books, as many states as practicable, and at the committee seek opportunities to of service in an advisory capacity ierever new lighting legislation is connplated.

It was voted that Prof. C. E. Clewell d Prof. O. H. Basquin be appointed embers of the Lighting Legislation mmittee.

Written reports on Section activities were received from J. R. Cravath, vice-president of the Chicago Section, G. H. Stickney, vice-president of the New York Section, and from Joseph D. Israel reporting for W. J. Serrill, vice-president of the Philadelphia Section.

The Council confirmed the appointment of Messrs. Geo. S. Barrows and E. L. Knoedler as members of the Exhibition Booth Committee (Gas).

Mr. H. Thurston Owens was appointed a local secretary of the Society in San Diego, Cal.

President Bond read a letter from Mr. M. Luckiesh on the illumination of school rooms. It was voted that the matter of school room illumination be referred to the Committee on Popular Lectures, and that a sub-committee be appointed by the chairman to prepare a lecture on the subject.

The following committee of five tellers was appointed to count the ballots of the 1914 election: Messrs. W. H. Rolinson, chairman; Thomas Scofield, L. J. Lewinson, T. H. Amrine, and J. P. Conroy; alternates: Messrs. G. G. Ramsdell and A. S. Ives.

Communications were received from Mr. P. R. Moses, of the City Club of New York; from the Cleveland Electrical Exposition, and from the Association Island Corporation.

Section Activities

CHICAGO SECTION

At a meeting of the Chicago Section held May 13 at the Monadnock Block, Mr. Wm. A. Durgin gave the fourth of his series of twenty-minute talks on the "Fundamentals of Illumination." Mr. J. R. Cravath presented a paper entitled "Brightness." Fifty-three members and guests attended the meeting.

June 10, a joint meeting with the

Chicago Section of the American Institute of Electrical Engineers and the Electrical Section of the Western Society of Engineers, Monadnock Block. Papers: "The Design of Illuminated Signs" by Prof. A. H. Ford of University of Iowa; "Chicago Street and Subway Lighting" by P. E. Haynes of the Chicago Electrical Department.

NEW YORK SECTION

The New York Section held a meeting in the auditorium of the new Lord and Taylor store, Fifth Avenue, New York, May 21. A paper entitled "Lighting of the new Lord and Taylor Store" was presented by Messrs. Bassett Jones and W. H. Spencer assisted by Edward E. Ashley, Jr. An informal dinner at Murray's preceded the meeting.

PHILADELPHIA SECTION

A smoker and mass meeting of all the scientific and engineering societies of Philadelphia and vicinity was held at the Continental Hotel Roof Garden, May 15. The following papers were presented: "Scientific Societies" by Dr. W. W. Keen, president, American Philosophical Society; "The Franklin Institute and the State" by Dr. Walton Clark, president of the Franklin Institute; "The Engineer as a Factor in Modern Progress" by Dr. Alex. C. Humphreys, president of Stevens Institute of Technology. Three hundred and eighty-one people attended the meeting.

PITTSBURGH SECTION

May 22 the Pittsburgh Section held a meeting at Nela Park, Cleveland, Ohio. Mr. C. L. Dows, who made an address of welcome, outlined the general work being done at Nela Park. The following papers were presented: "The Latest Developments in Mazda Lamps" by C. L. Dows; "The Lighting of Building Exteriors" by Ward Harrison. A collection of photographs showing uses of new incandescent lamp apparatus and a diffusing screen for interior photography was exhibited by Mr. M. Luckiesh. The first paper was supplemented by a series of lantern slide illustrations and a number of experimental incandescent lamps. After the presentation of the papers those present at the meeting inspected the lighting of the National Electric Lamp Association at Nela Park. Eighty-one members and guests attended the meeting.

New Members.

At a meeting of the Council, April 9, the following applicants were elected members of the Society:

BITNER, R. E.
Laboratory Instructor, Physics Department, Pennsylvania State College, State College, Pa.

BRICE, J. MONROE.
Representative Commercial Department, Boston Consolidated Gas Company, 24 West Street, Boston, Mass.

COTTON, HENRY F.
Superintendent of Public Lighting, 74 Merrion Road, Balls Bridge, Dublin, Ireland.

CRERAR, H. D. G.
Engineer in charge of Laboratory and Storehouse, Hydro-Electric Power Commission of Ontario, Toronto, Can.

INGALLS, L. O.
Lighting Engineer, City Electric Light Dept., 201 Civic Block, Edmonton, Alberta, Canada.

L'ESPERANCE, EUGENE M. R.
Manager, Bureau of Illuminating Engineering (Bronx District), New

York Edison Company, 362 East 149th Street, New York, N. Y.

Morris, H. W.
Chief Electrician, Grand Trunk Railway, Montreal, Can.

Northup, Edwin S.
Electrical Engineer, State Architect's Office, Albany, N. Y.

Spaulding, Arthur B.
New Business Assistant to Division Agent, Public Service Electric Company, 84 Sip Avenue, Jersey City, N. J.

Temple, Prof. Worrall E. S.
In charge of Electrical Engineering Work, Electrical Engineering Department, University of Pennsylvania, Philadelphia, Pa.

The following fourteen applicants were elected members of the Society at a meeting of the Council held May 14, 1914:

Babcock, Charles B.
Pacific Coast Manager, General Gas Light Company, 768 Mission Street, San Francisco, Cal.

Barnett, Edwin Lester.
Chief Electrician, Fort Bragg Electric Company and Union Lumber Company, Fort Bragg, Cal.

Bethke, Charles A.
Stenographer, Commonwealth Edison Company, 120 West Adams Street, Chicago, Ill.

Bond, F. A.
Special Inspector, United Gas Improvement Company, 1401 Arch Street, Philadelphia, Pa.

Farley, Charles A.
Manager, New England Lighting Company, 169 Congress Street, Boston, Mass.

Knapp, K. R.
Special Inspector, United Gas Improvement Company, 1401 Arch Street, Philadelphia, Pa.

Knoedler, E. L.
Assistant to General Manager, Welsbach Company, Gloucester, N. J.

Maluquer, Josep.
Chief Engineer, Ebro Irrigation & Power Company, Ltd., Apartado 491, Barcelona, Spain.

Patterson, H. G.
Lighting Salesman, Commonwealth Edison Company, 120 West Adams Street, Chicago, Ill.

Prichett, G. P.
Student, Iowa State College, Acacia House, Ames, Ia.

Riddock, G. H.
Secretary, The Bauer Fixture Company, 49 Jones Street, San Francisco, Cal.

Rindlaub, Dr. J. H.
Oculist and Aurist, de Lendrecie Block, Fargo, N. Dak.

Steel, Miles F.
Salesman, Benjamin Electric Mfg. Company, 348 Rialto Building, San Francisco, Cal.

Welsh, E. C.
Electrical Engineer, R. D. Kimball Company, 15 West 38th Street, New York, N. Y.

Sustaining Membership.

The Georgia Railway & Power Company, Atlanta, Ga., was elected a sustaining member of the Society at a meeting of the Council May 14.

I. E. S. Convention.

The eighth annual convention of the Illuminating Engineering Society will be held in Cleveland during the week of September 21. The convention will begin on Monday and last four days. An unusually good program of papers will be presented. On one day commercial and scientific sessions will be held simultaneously.

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ILLUMINATION OF SIGNALS.*

BY THOS. S. STEVENS.

Synopsis: This paper gives some notes on the problem of illuminating railway signal lenses. The development and use of kerosene, electric and acetylene lamps are discussed briefly.

The development of signal illumination has been along three definite lines: 1—kerosene lamps; 2—electric lamps; 3—acetylene lamps.

The first oil lamps and burners were crude affairs, and there were no ideas as to their requirements. At first little was known about the proper ventilation of the lamps, the different currents of air which might affect the flame, the proper vents to provide for the escape of the products of combustion or the effect of improper ventilation on the deterioration of the metal by rust. After a great deal of experimenting a method called a balanced draught was developed which solved the problem by providing for sufficient air to enter the lamp along a proper path so that combustion is provided for by a current of air which is partially warmed before coming in contact with the flame. At the same time proper paths have been provided for the exhausted air to escape without the possibility of sudden gusts of wind causing interior disturbances which might extinguish the flame. The result of all this has been that a steady flame free from smoke is provided and the condition of the air

* A paper to be presented at a meeting of the Chicago Section of the Illuminating Engineering Society, April 10, 1914.

The Illuminating Engineering Society is not responsible for the statements or opinions advanced by contributors.

inside the lamp is such that no moisture is precipitated under any weather conditions and consequently no rusting effects exist.

At first burners requiring attention every day were used. These, except for provisions for protecting the flame, were very similar to those used for domestic illumination and no particular development has been effected.

When more perfect combustion became possible a smaller burner was thought of, far more economical in every way, called the "long-time" burner. This burner, with a slightly larger oil cup, would successfully illuminate a signal for seven days if it were not for the difficulty experienced in keeping the top of the wick free from the crust which forms through lack of heat to consume the impurities in the oil. In order to take care of this condition, lamps are given attention twice weekly and even then are far more economical than the one-day burner on account of the decreased consumption of oil and labor. At first reflectors were used because it was feared that sufficient light would not be afforded, but this was soon proved to be wrong when scientific investigations were made. These investigations proved that the effective illumination of a lens is accomplished by a bright light on its center line and at the proper focal distance. It was found that as the effect of the reflector was to diffuse the light all over the lens, very little if any increased illumination was produced. The same fact explains why a one-day burner of far higher candle-power than the long-time burner, when tested by itself, gives so little added illumination when projected through a lens. Even with attention twice a week the burners would clog sometimes unless very high grade oils were used, and eventually the flame was increased slightly to increase the heat and the burners became very satisfactory for moderate grades of oil. Recently a tinsmith developed an inexpensive attachment for this burner which, by providing a small buffer for the retention of heat, supplements the natural combustion of the burner and so permits the use of a lower grade of oil obtained from an asphalt base. Tests are under way and there is every reason to believe they will be successful.

The construction of a wick for such a burner was a problem in itself. The flow of oil is so slow due to the small consumption

that, particularly with oils from an asphalt base, there was considerable filtration which eventually clogged most of the original designs. One ingenious lampman issued a dry vine stem which gave very good results, but the ultimate design was a piece of felt doubled over and sewn together with a small thread run through its center.

Naturally the long-time burner with its small flame is more liable to extinguishment by shocks and so it has not been used extensively for train markers or engine classification lamps in which some of the lenses are too large for proper illumination by a small flame. Added to this is the fact that labor for the care of these lamps costs nothing extra, and as a big saving is made on this account there has been no incentive to develop a long-time burner for this purpose.

Wherever practicable electric lights have been introduced. As in the case of the oil lamp, at first far more illumination was provided than was needed owing to the lack of knowledge of the properties of lenses. One of the first plants to be so equipped was at Twenty-first Street and Stewart Avenue in Chicago, where 16–candle-power lamps were used in high signals and 8–candle-power in dwarfs. No one stopped to make a comparison with the oil lamps which had been in use and which provided only a little over 1 candle-power. A reduction was soon made to 4–candle-power, then to 2 and now many small all-electric plants are lighted with 1–candle-power lamps which can be readily seen for a distance of two miles. Again, the principle of a small bright light in the center of a perfect lens at the proper focal distance is the cause. At the larger plants power is taken, of course, from dynamos direct or from some local supply, but on the smaller plants it is taken from storage batteries charged by gasoline engine-driven units. The energy consumption of the 1–candle-power lamps is so small that a very small battery will provide power and light for a fair sized plant for two or three days.

Recently extensive installations of alternating current electric signals have been made with, of course, the lamps lighted electrically. Because it seemed more economical, the lamps are burned all day because only 2–candle-power lamps are used and

the cost of the energy consumed is less than that of any control circuit which could be designed. There has been developed a relay for control of such functions based on the expansion and contraction of metal rods under the effect of light, but these have only been applied to channel buoys where considerable power is used and I do not know of the development of a relay small enough for use on signal circuits. It is probable that the cost would be too great even if it were developed.

Recently a Swedish firm has introduced an acetylene lamp which has received more or less attention. Acetylene gas for illumination of signals had been used before, but this firm developed a very ingenious valve to produce a flashing light which they claim renders signals more distinctive. This valve is of such simple mechanical construction that it is worthy of note in this paper. A permanent magnet is provided, the armature of which holds closed a valve which communicates with a small pilot flame. A chamber is provided in which gas accumulates till the pressure exceeds the pull of the magnet, when the armature is forced away and the gas in the chamber allowed to exhaust toward the pilot flame. The effect is a flashing light which can be very easily controlled by allowing the armature to come to rest nearer or farther away from the permanent magnet, so increasing or decreasing the pressure necessary to force it away or by opening or closing a valve to the main supply, decreasing or increasing the time required to bring the pressure in the chamber to the strength required to overcome the armature pull.

Lenses have been brought to such a perfection to-day that it has been found practicable to properly illuminate signals so that the different colors can be readily distinguished in daylight at 2,000 feet (609.6 m.). Of course, this is only possible where electric light can be used, but it provides a very cheap and efficient way to signal electric roads where plenty of power is available at a cheap rate. All the complicated mechanisms necessary for the mechanical operation of signal arms are eliminated and replaced by simple electrical circuits which are far more efficient and economical to maintain. In the majority of cases two 25-watt lamps are used behind an 8-inch lens. It would appear that the problem with this type of signaling is to provide a light

signal sufficiently visible in bright sunlight which will not make the signal too prominent at night.

The subject of the illumination of signals is so intimately connected with the development of lenses that no paper can present the question in its true light without referring to this feature, which is to be made the subject of another paper* this evening, prepared by Dr. Churchill, who is responsible for so much of the development. Were it not for this neither the long-time burner nor the low-power electric lamp would have been possible, so that one should study both papers in order to form some idea of the work which has been done to accomplish the successful, efficient and economical illumination of railway signals.

DISCUSSION.

MR. W. N. MANUEL (Communicated): This subject is and for many years has been one of keen interest to signal men generally. With the advent of the "Light Signal" referred to in the paper, it is probably due for some lively development in the near future.

Mr. Stevens has covered the oil lamp proposition quite fully and added to the knowledge of many a means of overcoming the effects of poor oil by retaining heat in a small buffer. This, if successful, will overcome the only remaining objection to the use of long-time burners.

Relative to electric lights, it may be mentioned that the tendency toward the use of low voltage lamps to gain the advantage of a stronger filament, less susceptible to the effects of shocks and vibration resulting from the impact of signals, is quite prevalent. Also, the burning of two low candle-power lamps in multiple or alternately through the coils or points of an emergency relay, for the purpose of reducing the chances for a light failure, is being extensively used.

The subject of lenses is one of such complexity and may only be properly discussed by those having made its study a specialty. However, it may be well to state that good results are being obtained by the use of inverted lenses with plain glass covers at points where it is desired to spread the beam of light and to improve the view of the indication from all points on a curve.

* TRANS. I. E. S., Vol. IX p. 371.

As this arrangement provides a dead air space between the lense and the cover, its use may also contribute much towards overcoming the effects of frost.

MR. BURT T. ANDERSON: The energy consumption of a 1-candle-power lamp is small, yet the total light load may amount to a large per cent. of the total load at the plant. On one installation the signal load was 10 per cent. and the lights 20.1 per cent. of the total load. On another installation the signal load was estimated at 25 per cent. and the lights 75 per cent. of the total load. The use of a low wattage 1-candle power, 110 volt lamp, if such a lamp was on the market, would greatly reduce the light load at plants.

MR. C. C. ANTHONY (Communicated): The Pennsylvania Railroad is proceeding with the electrification of its line for twenty miles west from Philadelphia, with over-head construction for single-phase alternating current propulsion. Light signals were, at first, considered in connection with this work, largely because it seemed likely that they could be placed lower on the signal bridges than semaphores so that the view would be less obstructed by the overhead construction. Subsequently it was decided that the over-head construction should consist entirely of wires, with cross catenaries for support of the trolley-wire catenaries, so that the view would hardly be obstructed at all. In the meantime, however, so many promising features of light signals have been developed that the experiments have been continued and it is not unlikely that such signals will be installed on this section.

MR. G. L. WATERS (Communicated): The question of oil is one which requires constant study in the developing of lamp-burners. Years ago practically all the illuminating oil came from the Pennsylvania coal fields. In the meantime the tendency has been westward in the development of oil fields, until now the fields include Ohio, Indiana, Illinois, Kansas and Texas. Refiners and lamp makers have had to give careful attention to the variation in the crude oil. The difference in the crude oil requires different methods of treatment for the oil, and at times modifications in the ventilation of the lamp burners to secure proper combustion.

Usually upon entering a new oil field, there is more or less trouble with the oil until the refiners have become thoroughly familiar with the handling of it. But at the present time the oil used with the improved burners is, as a general proposition, giving good results.

The wick is a feature to be carefully considered. Experience has shown that the center-core long-time burner has proved the most satisfactory.

Mr. L. K. Rann (Comunicated): One point that I would like to bring out is the matter of alignment of signal lamps. This feature has always called for efficient maintenance in order to maintain a good night indication of signals, for unless the alignment be given proper attention the indication to the enginemen will be found in the majority of cases pointing out across the field or anywhere except in the direction desired. The most efficient method of maintaining this alignment heretofore has been frequent night trips over these lamps. An alignment lamp has been made up in the form of a transit. By placing this lamp on a lamp bracket in daylight and taking a sight through it one may see where the center of illumination would be with reference to the rail.

It appears to me that a very simple an inexpensive arrangement could be added to the lamps by lamp manufacturers so that any lampman or repairman could look through openings properly designed to ascertain whether a lamp had proper alignment by daylight. This, I believe, would help greatly in this matter. Of course, the freznel lens has done a great deal to increase the efficiency of the illumination along this line.

BRIGHTNESS.*

BY J. R. CRAVATH.

Synopsis: The first part of this paper gives some of the elementary principles of brightness measurements and calculation from our well known units and with well known apparatus. Tables are given showing the brightness in candle-power per square inch of a large number of illuminated surfaces and light sources. Comments bring out some interesting points in the tables. Results of testing some comfortable and uncomfortable brightness conditions are given. The author has investigated the brightness of pencil and ink marks and the paper behind them and shows why pencil marks are sometimes invisible. Distribution of brightness within the range of vision is one of the most important factors in comfortable illumination.

So far in illuminating engineering we are much more accustomed to thinking in terms of illumination intensity or foot-candles than in terms of the brightness of objects within the range of vision produced by this illumination. Considerable attention has been given to the brightness or intrinsic brilliancy of artificial light sources, but brightness conditions as they exist around us every day under satisfactory conditions of illumination should have much more study.

The relative brightnesses of the surfaces within the range of vision together with the total amount of light emitted from them are the most important factors in comfortable illumination. Differences in the amount and distribution of surface brightness within the range of vision constitute the fundamental differences between methods of illumination.

ELEMENTARY PRINCIPLES AND CALCULATIONS.

Brightness is the quality or state of radiating, reflecting, or transmitting light. If an object is visible it has a certain degree of brightness, otherwise we could not see it. One good definition of illuminating engineering would be that it is the science and art of production and distribution of brightness.

The term "surface brightness" has been frequently used of

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late as applied to the brightness of surfaces illuminated by various sources. The word "surface" seems to be superfluous. The simple word brightness used in its literal sense covers all that is intended to be covered by the term "surface brightness." The term "brightness," which I have selected as the title of this paper, will be used as an equivalent of the terms "intrinsic brilliancy" and "surface brightness."

If a surface appears bright from its own light, as for example the filament of an incandescent lamp, the flame of an arc or a gas burner, or the tube of a mercury-vapor lamp, we call it a primary source of light. If its brightness is due to reflected or transmitted light it is called a secondary source of light.

Mathematically the brightness of a surface is the amount of light emitted per unit of area. It may be expressed in candle-power per square inch, candle-power per square foot or candle-power per square meter. In this country where the foot-candle is the common unit of flux density or illumination intensity, brightness could be expressed most conveniently in candle-power per square foot were it not that this involves so many decimal points in dealing with the brightness of ordinary surfaces under artificial light. I have therefore adopted candle-power per square inch as the unit of brightness in this paper.

Brightness unlike illumination is independent of distance from the source. A given patch of white wall back of this platform in our meeting room appears just as bright to a man seated in the back of the room as to one on a front seat. However, the area of the image of this patch of wall on the retina of the eye varies inversely as the square of the distance from the eye to the patch of wall, hence the illumination or flux density which falls upon the eye from the patch of wall varies inversely as the square of the distance. In other words the decrease in illumination with increased distance is not due to any decrease in brightness per square inch of surface, but to decrease in the size of the image on the retina.

A surface such as the tube of a mercury-vapor lamp or the filament of an incandescent electric lamp appears equally bright as viewed from any angle. That is, its surface brightness as viewed from any angle will be the same. However, the surface

presented for a candle-power measurement is not the same at all angles and the candle-power decreases in the same proportion as the decrease in surface presented. Hence the low end on or tip candle-power of incandescent or mercury-vapor lamps.

A perfectly diffusing reflecting surface is one which with a given illumination presents an equal brightness in all directions. In this respect it is similar to an incandescent surface or gas filled tube lamp.

In Fig. 1 is shown the distribution of candle-power and distribution of surface brightness about a perfectly diffuse reflector surface or an incandescent or a primary source of light (a) plotted as polar co-ordinate curves. The candle-power curve is

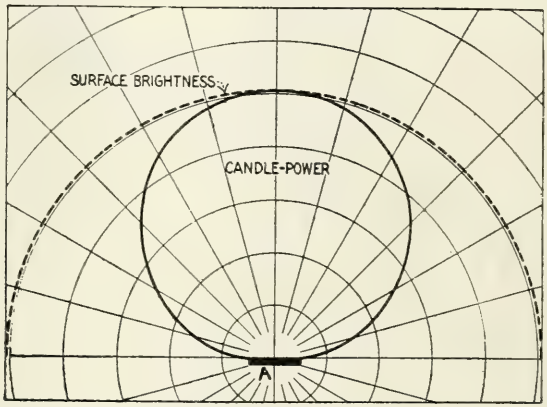

Fig. 1.—Distribution of candle-power and surface brightness in any plane normal to a perfectly diffusing surface.

a circle with the surface (a) tangent to it while the surface brightness curve is a semi-circle with (a) at its center.

If instead of a perfectly diffusing surface we have a perfect specular reflecting surface such as a mirror, the candle-power curve instead of being a circle becomes a point and the surface brightness curve likewise becomes a point since there is neither candle-power or brightness except in one direction. In this case the brightness of the reflected light from the mirror is the same as that of the source less the absorption of the mirror.

The brightness of a surface varies directly as the incident illumination and as the reflecting power of the surface. If the

surface is perfectly diffusing the brightness can be calculated in our common units by the formula:

$$b = \frac{i\,k}{3.14}$$

where b is the brightness in candle-power per square foot;
i is the illumination in foot-candles upon the surface;
k is the coefficient of diffuse reflection, or per cent. of incident light reflected by the surface.

Since we are dealing with foot-candles the foregoing results give candle-power per square foot.

The simple rule is: candle-power per square inch equals incident foot-candles times coefficient of diffuse reflection divided by 452.

While the foregoing rule applies to surfaces which are perfect diffusers it must be remembered that such surfaces are seldom encountered in practise. White blotting paper, plaster of paris and etched opal glass commonly called milk glass come the nearest to perfect diffusion of any surfaces. Most surfaces give some of the effects of diffuse reflection combined with specular reflection.

In the practical measurement of brightness a photometer which has no diffusing plates or surfaces between the surface to be measured and the eye is used. The brightness of the surface must appear directly on the photometric screen without the interposition of anything but clear glass or mirrors between the eye and the surface.

The method is to expose the surface, the brightness of which is to be measured, to one side of the photometer screen, the standard lamp in the photometer illuminating the other side of the screen. As already explained it is immaterial at what distance the surface of which the brightness is to be measured may be from the photometric screen as the brightness is independent of distance. It is, however, important that the surface on which the brightness is to be measured occupies the whole area of the spot on the photometric screen. A photometer is in reality an instrument for comparing the brightness of two surfaces. If, therefore, when we look into the photometer we are able to see the direct or reflected brightness of the surface we wish to measure

on one side of the screen and the brightness caused by the photometer lamp on another part of the screen, we can obtain a balance of equal brightness by the ordinary method of photometric setting. In order to calibrate the photometer so as to give a proper value to the scale readings thus obtained it is only necessary to set up the photometer in a laboratory and take a brightness reading of some evenly illuminated surface of known area and candle-power, such as plaster of paris or milk glass. The candle-power per square inch of the milk glass or other surface being known, the proper factor by which to multiply the photometric scale reading, to obtain candle-power per square inch, can be determined by dividing the candle-power per square inch of the standard surface by the scale reading obtained on the photometer, when the photometer screen is balanced against the standard surface. This applies only to a photometer with the usual logarithmic scale.

In making brightness measurements of different parts of a room as they appear to the eye, convenience and portability of the photometer are very essential, unless the method is to be so cumbersome that it is of little use. The photometer must be pointed or aimed directly at the surface to be measured. Although appreciating the importance of surface brightness measurements for several years the writer made but very few such measurements, until the appearance on the market, September, 1913, of the new small type Sharp-Millar photometer. This instrument has the advantage of being small enough so that it can be readily held in one hand and the observer can sit or stand in a comfortable position and aim the instrument at the surface he wishes to measure. As a telephone receiver takes the place of a mil-ammeter with this photometer and but two dry cells are needed for operation of the photometric lamp it is a very simple matter by taking the photometer in one hand, a battery box in the other and the telephone receiver in a pocket to move around from one place to another and get numerous readings within a short space of time. I prefer to use this photometer by removing the elbow tube altogether and substituting a short, straight, blackened tube for the elbow tube so that the light from the surface to be measured shines straight into the center spot of the

modified Bunsen screen of the photometer. This screen consists of a spot of clear glass, through which the surface under test is viewed, surrounded by a mirror which reflects the diffused light of the photometer lamp. It is of course much easier to aim the photometer tube when looking directly at the surface to be measured than when holding the photometer at right angles to the direction of aim. Surface brightness measurements taken in this way are necessarily rough and approximate because the differences in colors which have to be compared on the photometric screen are greater than those commonly experienced in illumination and candle-power measurements. However, the results are sufficiently accurate for present practical purposes, where no fine distinctions are yet necessary.

COMMENTS ON TABLE I.

The accompanying table is a compilation of figures on the brightness of various primary and secondary sources of light compiled from various published sources and from measurements made by the author.

The first striking thing about such a table is the enormous difference in brightness within the same field of view to which the eye is subjected. Take for example a small room illuminated by a clear tungsten incandescent lamp; the filament presents a brightness of 1,060 candle-power per square inch while the walls may easily be as low as 0.00015 giving a ratio of about 7,000,000 to 1. A clear nitrogen filled tungsten lamp with opaque reflector in a dark walled factory of course presents much more than this contrast to the eye. With clear globes, arc lamps are even worse than this.

The sun at 30° elevation with 500,000 candle-power per square inch is surrounded by blue sky having a brightness of 2.15 or a ratio of only 230,000 to 1.

Discomfort or injury to eyes is not due altogether to the contrast in brightness between adjacent surfaces within the range of vision, but it is beyond question that such contrasts play a very important part in comfortable and hygienic conditions for the eye. In addition to the influence of contrast of brightness the total amount of light flux received from the brightest areas is important. Give the eye time to adapt itself and it works

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comfortably over a great range, but it is unreasonable to expect no harm to follow continued exposure to brightness contrasts far greater than those found in nature.

TABLE I.

Approximate Brightness of Various Primary and Secondary Light Sources.

Natural sources	Authority*	Candle-power per square-inch
Sun at Zenith	2	600000.000000
Sun at 30° elevation	2	500000.000000
Sun on horizon	2	2000.000000
Sky, clear blue or hazy	5	2.150000
Sky, overcast, no blue	5	4.340000
Sky, blue predominating, clouds generally cirrus	5	3.050000
Sky, clouds predominating, generally cumulous	5	3.960000
Sky, no blue, storm present or near	5	1.390000
Sky, very heavy clouds	3	0.200000
Sky, very heavy clouds and smoke	3	0.100000
White paper 70 per cent. coefficient of diffuse reflection in 8,000 foot-candles of sunlight	4	12.360000
White paper, 70 per cent. coefficient of diffuse reflection in 300 foot-candles, skylight near large window	4	0.463000
Wall, 50 per cent. coefficient diffuse reflection near large window in 300 foot-candles	4	0.330000
Pavement, 10 per cent. coefficient diffuse reflection in 8,000 foot-candles of sunlight	4	1,770000
White letter paper on desk 6 feet (1.83 m.) from large window. Cravath's office, light clouds	3	from 0.170000 to 0.086600
White paper under 3 foot-candles, same desk, very cloudy day	3	0.004630
Walls of rooms in suburban residence, daylight	3	from 0.000076 to 0.086000

Artificial sources	Authority*	Candle-power per square-inch
Crater of carbon arc	1	84000.000000
Flame arc	2	5000.000000
Calcium light	2	5000.000000
Magnetite arc	1	4000.000000
Nernst glower	1	3010.000000

TABLE I.—(*Continued*)

Artificial sources	Authority*	Candle-power per square inch
Incandescent electric lamps:		
Tungsten 1.25 watts per hor. candle-power	1	1060.000000
Carbon filament 2.5 watts per hor. candle-power	1	625.000000
Carbon filament 3.5 watts per hor. candle-power	1	375.000000
25-watt frosted tungsten lamp, side	1	6.000000
25-watt frosted tungsten lamp, tip	1	1.670000
100-watt tungsten lamp in 10-inch (25.4 cm.) opal ball	4	0.630000
150-watt tungsten in Monolux art glass		0.345120
Flames:		
Acetylene	2	from 40.000000 to 60.000000
Acetylene 1-foot burner	1	53.000000
Acetylene 0.25-foot burner	1	33.000000
Welsbach mantle	1	31.000000
Kerosene	1	9.000000
Candle	2	from 3.000000 to 4.000000
Open fish tail gas flame	1	2.700000
Vapor tubes:		
Cooper-Hewitt mercury-vapor lamp	1	14.900000
Moore carbon dioxid tube	2	0.500000 to 1.000000
Artificially illuminated surfaces:		
White paper illuminated with 3 foot-candles	4	0.004630
Ceiling over indirect lighting fixtures; usual range	3	from 0.090000 to 0.006280
Walls of typical room with ample artificial light	3	from 0.004522 to 0.000015

The iris of the eye expands or contracts the pupil mainly to adjust for changes in brightness of the central part of the field of vision. Great differences in brightness therefore are likely to put considerable work on the iris and its controlling nerves in adapting the size of pupil to the varying brightness falling on the central part of the retina as the eye shifts its position. In addition to this is the possible irritation of the retina under such

* 1. Ives & Luckiesh, *Electrical World*, Feb. 16, 1911.
2. Bell, Art of Illumination.
3. Tested by Cravath.
4. Estimated by Cravath.
5. American Luxfer Prism Co., 1897, Chicago experiments, Illuminating Engineering Society Baltimore lectures, p. 652.

abuse. The variations in brightness from day to night to which the eye can adapt itself are enormous when expressed in figures. It has been shown in the tests by Mr. L. J. Lewinson[1] on natural illumination that foot-candles of natural illumination measured in New York City during August and September vary from about 12,000 normal to the sun's rays at mid-day in brightest sunshine, down to about 0.014 on moonlight and 0.001 on starlight nights. As the brightness of any given surface varies according to the incident foot-candles it will be seen that we have a natural variation in 24 hours of 12,000,000 to 1, taking Mr. Lewinson's figures as a basis. This is the variation caused by the variation in illumination alone. To this should be added the variation due to difference in the reflecting power of surfaces. This, however, is much smaller than the variations caused by the changes in illumination. If we assume we can see a certain surface by starlight which has a 10 per cent. coefficient of reflection we could have a difference in surface brightness between such a surface under starlight and a piece of white paper with 80 per cent. coefficient of reflection under mid-day sun of 8 times the 12,000,000 or 96,000,000 to 1.

Differences in brightness caused by differences in reflecting powers of surfaces are small as compared with the differences caused by the variations in illumination. The blackest surface we know of, namely, black velvet, reflects about 0.5 per cent. and the whitest paper or plaster about 85 per cent. so that the difference between the white paper and black velvet under a given illumination will only be 170 to 1. This, however, is an extreme case. Very few black surfaces with which we are acquainted reflect less than 4 per cent. which will bring the ratio down to 20 to 1 and usually the differences on ordinary written and printed pages between the letter and the paper background are less than 10 to 1, as shown later.

It is notable that the brightness of a ceiling with an indirect lighting system as observed by an occupant of the room with the head in a normal position is considerably less than would be the case if ceilings were generally perfectly diffuse reflecting surfaces. The actual brightness as measured in various indirect

[1] TRANS. of the Illuminating Engineering Society, Vol. 3, p. 484, 1908.

lighting installations is considerably less than that calculated from the photometric curves of the units used on the assumption that the ceilings are perfectly diffusing reflectors.

The ordinary ceiling brightness to which the eye is exposed with indirect lighting in the ordinary range of practise is at its maximum about that of an exceedingly dark cloudy sky.

The brightness contrasts to which the eye is subjected with indirect lighting and with good natural light from skylights and windows are in general very similar though there is much difference in the absolute values and in the relative positions of the brightest surfaces. For further information on this question the readings taken at various positions as given later should be studied.

I regret being unable to give more figures on brightness conditions in rooms by daylight. This is difficult to study under conditions existing most of the time in the down town district of Chicago because of the rapid changes in sky brightness which are the rule rather than the exception. As can be seen from the brightness table the sky varies greatly in brightness according to the character of the clouds. The only way to secure sky conditions sufficiently constant to permit measurements of the brightness of interiors with the natural illumination of the sky would be to select a cloudless day in a location free from smoke, haze and fog.

Sky brightness during the middle of the day varies from 4 or 5 candle-power per square inch with very light clouds down to 0.2 or even lower, and of course decreases as sun gets lower. Clear blue sky is roughly 2 candle-power per square inch. Only those who have attempted to get illumination or brightness measurements with natural light can appreciate the large and rapid fluctuations which take place, which are ordinarily unnoticed in our daily life.

The brightness of a sheet of white bond letterhead paper laid flat upon my office desk viewed from my usual position at the desk as measured in five successive readings following each other as rapidly as they could be taken were 0.170000 candle-power per square inch maximum and 0.086000 minimum. These readings were taken about 10 A. M. with light hazy clouds and intermittent

sunshine. Some of the lowest readings were taken when there was the most sunshine. The sun was not visible from the desk which was 6 feet (1.83 m.) from a large window and was exposed to a considerable area of sky and white enameled brickwork being located on the 16th floor of a 17-story building in a room frequently commented upon for its good natural light. Simultaneous readings of sky brightness would probably have shown from 2 to 4 candle-power per square inch. Assuming a 70 per cent. coefficient of reflection for the letter paper these readings would correspond to a maximum of 109 and a minimum of 55 foot-candles on the desk. The maximum is roughly 25 times what we would consider ample artificial illumination for office and desk work.

Assuming a sky brightness of 4 candle-power per square inch the sky was 23 times as bright as the paper, a ratio of brightest visible surface to paper of about the same order of magnitude as with indirect lighting.

POSITION STUDIES.

One of the most profitable ways to study brightness conditions is to sit down with a photometer in a position which experience has shown us to be comfortable or uncomfortable to the eye and measure the brightness of different surfaces within the range of vision. I present herewith a number of such studies in the form of tables entitled Positions 1, 2, 3, etc.

Position 1 is a condition in a typical small room with a single tungsten lamp in a deep reflector of prismatic glass at the ceiling. The greatest contrast presented to the eye is in the ratio of 1 to 6,557. This contrast in itself is not so bad perhaps as the contrast between the frosted tungsten lamp and the ceiling alongside of it which is as 1 to 890. If a clear tungsten lamp with a brightness of 1,000 to 1,200 candle-power per square inch were used instead of the frosted tungsten the brightness ratios of course would be from 170 to 200 times greater. Positions 2, 4, 7 and 11 are typical of modern indirect lighting installations while positions 1, 6, 8, and 10 are typical of modern direct lighting systems. Position 12 is typical of a semi-indirect office installation with rather dense art glass[2] bowls.

[2] Monolux.

POSITION 1.

Seated near east wall of a room 9 x 12 ft. (2.74 x 3.66 m.) facing center. Cream ceiling, light green walls lighted by one 60-watt tungsten lamp at center of ceiling in prismatic extensive reflector.

Surface	Brightness in candle-power per square-inch	Ratio to brightest surface in view
Frosted tungsten lamp tip estimated......	6.000000	1 : 1
North window shade (green)............	0.000915	1 : 6557
Wall above door opposite................	0.003480	1 : 1724
Ceiling alongside of lamp................	0.006750	1 : 890
Wall west of northwest window..........	0.001730	1 : 3520
On door opposite	0.003970	1 : 1510
On ceiling one-half way center to west wall	0.002320	1 : 2590

POSITION 2.

Seated facing center, and about one-half way center to east wall, in 12 x 16 ft. (3.66 x 4.87 m.) room; ceiling and walls light cream; indirect lighting with one 60-watt tungsten lamp in center.

Surface	Brightness in candle-power per square-inch	Ratio to brightest surface in view
Center of ceiling over indirect fixture....	0.006280	1 : 1
Middle of north wall....................	0.001725	1 : 3.64
Ceiling one-half way center to north wall	0.003370	1 : 1.87
Floor, center of room..................	0.000735	1 : 8.56

POSITION 3.

Daylight 8 A. M., very heavy clouds. Seated in center of 12 x 16 ft. (3.66 x 4.87 m.) room looking toward east window. Ceiling light cream, walls brown.

Surface	Brightness in candle-power per square-inch	Ratio to brightest surface in view
Eastern sky	0.193000	1 : 1
Wall over piano.........................	0.000225	1 : 880
Manila scratch paper on music rack opposite middle of window................	0.000288	1 : 670
Wall just south of window..............	0.000076	1 : 2540
Ceiling 4 ft. (1.22 m.) from window......	0.000846	1 : 228
Floor 4 ft. (1.22 m.) from window.......	0.000117	1 : 1650

Position 4.

Seated in northeast corner and facing center of a room 12 x 16 ft. (3.66 x 4.87 m.); cream ceiling, brown walls, indirect lighting from center with 140 watts in tungsten lamps.

Surface	Brightness in candle-power per square-inch	Ratio to brightest surface in view
Brightest spot on ceiling over indirect fixture	0.008600	1 : 1
Wall above picture rail in southwest corner	0.000045	1 : 191
Wall below picture rail, southwest corner	0.000015	1 : 573
Ceiling half way center to south window	0.000440	1 : 9.5
Fireplace	0.000054	1 : 159

Position 5.

Seated at west side of a dining room table, facing east. Room 12 x 16 ft. (3.66 x 4.87 m.), cream ceiling, brown walls. Lighted by 25-watt tungsten lamp over center of table in prismatic extensive reflector covered with silk dome.

Surface	Brightness in candle-power per square-inch		Ratio to brightest surface in view
Brightest part of fixture	0.428000		1 : 1
Center of table	0.011250		1 : 38
East wall	0.000036	(fixt.)	1 : 11900
		(table)	1 : 313
Ceiling over east edge of table	0.003680	(fixt.)	1 : 116.2
		(table)	1 : 3.05
West edge table	0.005480	(fixt.)	1 : 78
		(table)	1 : 2.05

Position 6.

Seated at a desk in a general office with green ceiling and walls lighted with frosted tip tungsten lamps in satin finish prismatic reflectors at ceiling.

Surface	Brightness in candle-power per square-inch	Ratio to brightest surface in view
Frosted tungsten lamp	6.000000	1 : 1
Ceiling alongside of reflector	0.010000	1 : 600
Ceiling between lamps	0.000630	1 : 9520

Position 7.

Seated facing a very large general office with very light cream ceiling and very light buff walls and pillars lighted indirectly with one 100-watt tungsten lamp in the center of each 10 ft. (3.04 m.) square. Reflectors about 5 ft. (1.52 m.) from the ceiling.

Surface	Brightness in candle-power per square-inch	Ratio to brightest surface in view
Brightest part of ceiling..................	0.009400	1 : 1
Darkest part of ceiling..................	0.007150	1 : 1.32
Pillars and walls	0.003120	1 : 3.01

Note—Looking up at ceiling from underneath a lighting unit showed a surface brightness of 0.015620 candle-power per square-inch, but this is not the brightness to which the eye is exposed.

Position 8.

Seated next to aisle in Western Society of Engineers auditorium, opposite rear columns. Looking forward or north. Lighted by 4 chandeliers with frosted lamps and concealed trough stage lights.

Surface	Brightness in candle-power per square-inch	Ratio to brightest surface in view
Frosted lamps (estimated)	6.000000	1 : 1
White screen back of stage...............	0.004870	1 : 1230
Brown curtains back of stage............	0.000495	1 : 12100
Upper white wall beside curtain.........	0.004950	1 : 1210
Wall nearest northeast chandelier........	0.013500	1 : 445
Ceiling just south of northeast chandelier	0.072500	1 : 82.8
Low portion of ceiling in shadow.........	0.000205	1 : 29300

Position 9.

Same as position 8, but with lamps in reflectors above skylights substituted for chandeliers.

Surface	Brightness in candle-power per square-inch	Ratio to brightest surface in view
Skylight	0.107100 to 0.214200	1 : 1
Center of white screen back of stage.....	0.003825	1 : 56
Brown curtains back of stage............	0.000342	1 : 627
Upper white wall beside curtain..........	0.003375	1 : 63.6
Wall nearest northeast chandelier........	0.000170	1 : 1126
Ceiling just south of northeast chandelier	0.000322	1 : 665
Low portion of ceiling in shadow.........	0.000105	1 : 2040

POSITION 10.

Seated at bookkeeper's desk 8 ft. (2.44 m.) from south wall in room 19.5 x 24.5 ft. (5.94 x 7.46 m.) north and south, 10.5 ft. (3.2 m.) high, looking north. Direct lighting from 6 distributed outlets with bowl-frosted tungsten lamps at ceiling with dense opal reflectors. Nearly white ceiling, light yellow walls

Surface	Brightness in candle-power per square-inch	Ratio to brightest surface in view
Tungsten lamp, frosted tip (estimated)...	6.000000	1:1
Center of north wall 7.5 ft. from floor....	0.004520	1:1330
East wall opposite northeast outlet........	0.009700	1:619
White blotting paper on desk (coefficient of diffuse reflection = 70 per cent.)	0.006552	1:914

POSITION 11.

Same as position 10, but with four indirect lighting units.

Surface	Brightness in candle-power per square-inch	Ratio to brightest surface in view
Ceiling over fixtures	0.053618	1:1
Center of north wall 7 ft. (2.13 m.) from floor	0.006460	1:8.3
Upper east wall opposite fixture..........	0.013404	1:4
White blotting paper on desk (coefficient of diffuse reflection = 70 per cent.)	0.006552	1:8.19

POSITION 12.

Same as position 10, but with four indirect lighting units.

Surface	Brightness in candle-power per square-inch	Ratio to brightest surface in view
Fixture bowl, art glass..................	0.345120	1:1
Ceiling over fixture	0.023610	1:14.6
Center of north wall 7 ft. (2.13 m.) from floor	0.004522	1:76.4
White blotting paper on desk (coefficient of diffuse reflection = 70 per cent.)	0.006552	1:52.6

Position 3 was measured because it represents an uncomfortable daylight position with which most of us are familiar, namely, that of a room receiving all of its light from one window and that window of insufficient area to properly illuminate the room.

It is well known how difficult it is to distinguish the features of a person seated between a window and the observer. In fact

the difficulties are frequently such as to soon cause pain in the eyes or headaches. The manila scratch paper on the music rack as mentioned in position 3 was intended as an approximate substitution for a face of a person placed in a similar position. It will be noted that the sky against which it was seen was 670 times as bright. Further comment is unnecessary when one considers that the contrast between an ordinary black pencil mark and paper is only 1 to 6.

Position 5 was measured because it represents comfortable dining room table lighting from a silk covered dome. The contrast appears to be rather great, but it must be remembered that the brightest surface in the room is only 0.428 candle-power per square inch and there was not much area exposed even of this brightness. Whatever may be the explanation the conditions are usually considered comfortable.

Position 6 shows conditions in a large general office where the writer was called in on account of the dissatisfaction with the artificial lighting. Many of the employees were wearing eye shades and the complaint was general.

Positions 8 and 9 show the brightness conditions existing in the Western Society of Engineers' auditorium where our meetings are held. Position 8 shows the illumination when lighting with chandeliers with unshaded frosted lamps, and position 9 lighting with reflectors pointed in a general forward direction above the skylights. The main practical difficulty with the latter installation has been the excessive amount of soot and dirt which collects in a short time on the skylight, due to openings in the upper skylight. It is also of interest to note that the brown curtains back of the stage which were installed at the earnest request of some of our members to reduce the brightness of the large expanse of white plastered wall forming the stereopticon screen back of the platform, have reduced the brilliancy to about one-tenth that with the curtains removed. As one is usually trying to see the face of a speaker against this background the desirability of reducing the brightness of the background by these curtains is evident and has been a matter of personal experience to most of the members of the Chicago Section.

BRIGHTNESS OF PAPER, PENCIL AND INK MARKS.

Fig. 2 presents the results of tests which show clearly why indelible pencil marks are invisible at certain angles under certain light conditions. This shows the results of certain surface brightness measurements taken of three kinds of surfaces: first, on a piece of plain white bond letter paper (the author's regular letterhead); second, the same paper covered with indelible pencil marks; third, the same paper covered with black pencil marks; fourth, the same paper covered with common blue writing ink. The illumination was constant in all these tests. One test was

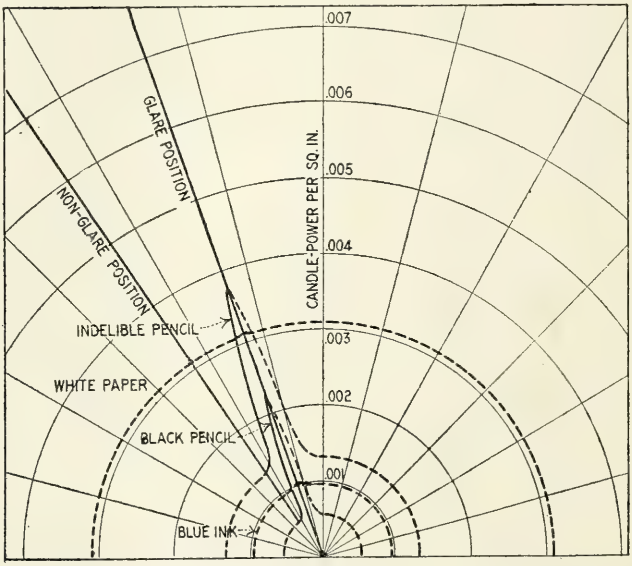

Fig. 2.—Brightness of white bond paper and same paper coated with indelible pencil, black pencil and writing ink at glare and non-glare angles.

made on each surface in the "glare position" where maximum specular reflection was received from a bare 50-watt carbon filament lamp mounted horizontally 38 in. (0.96 m.) above the surface measured. The results are plotted on polar co-ordinate paper, the distance from the center indicating the relative brightness. My measurements covered only the solid portions of these curves, the remaining dotted portions being plotted on the somewhat incorrect assumption that these surfaces are perfect diffusers except at the angle of glare or specular reflection.

It will be seen that at the angle of glare the indelible pencil mark is considerably brighter than the paper and that there is a position in which it is of the same brightness of the paper. In other words if this test is correct the indelible pencil marks will become invisible at certain angles just before the maximum glare is received and will re-appear brighter than the paper as the paper is tilted nearer to the maximum glare position. By taking a piece of paper with indelible pencil marks upon it under a small light source we find that this is exactly what occurs. We also find that there are positions in which a common black pencil mark is not as clearly visible as in others and the reason for this is also made clear by the tests, Fig. 2, as we see that while the black pencil is roughly only one-sixth as bright as the white paper at non-glare positions it is about two-thirds as bright as the paper at the glare position. No wonder we can not see the pencil marks as plainly. It is very interesting to note that common writing ink does not have the glare characteristics of pencil marks and is very similar to the paper on which it is placed in that it shows but slight increase of brightness in the glare position. The brightness of the plain white paper at positions of maximum glare is probably greater than my measurements show because of the difficulty of getting accurate measurements of the glare spot with a paper as diffusely reflecting as the bond paper used.

While the ink is considerably brighter than the black pencil at non-glare positions it is much less bright at the glare position and therefore much more easily read. The inferiority of the indelible pencil at all positions is very evident.

Time has not permitted experiments on surfaces covered with printers' ink and compressed as in the ordinary printing process. These would perhaps show results something like the black pencil but the results would probably be much influenced by the character of the paper. There is some reason to believe that more of our trouble with specular reflection or glare from paper than we have supposed is due to the characteristics shown by the pencil marks in Fig. 2, namely, to the surface brightness of the ink or pencil surface being nearly equal to the brightness of the surrounding paper. Some reports published by M. Luckiesh[3]

[3] An analysis of glare from paper, *Electrical Review*, June 1, 1912.

indicate roughly that gloss finish paper is about 1.5 times as bright at the angle of glare as at the other angles. The few rough experiments that I have made along this line indicate that this ratio is the upper limit and that it is as a rule less than this amount. This is rather surprising in view of the annoying effect of glare from paper.

We are accustomed to think of printing or pencil marks upon white paper as presenting the maximum contrast or difference in brightness to the eye that we can conceive. Fig. 2 shows that the brightness ratio at non-glare positions is only about 1 to 6 and it is doubtful whether a brightness ratio of 1 to 20 is often exceeded in printed or written matter. Comparing this with the brightness ratios shown to commonly exist around us in the data given elsewhere in this paper makes the contrast on a printed or written page seem rather insignificant. Of course the reason the letters on a printed page present such a contrast to us is that they are closely adjacent to the brighter paper surface and the line is sharply drawn between them. This brings home to us again the well known principle that the eye can only judge accurately differences in brightness if the surfaces of which the brightnesses are to be compared are brought closely together. The sharper and more clean cut the line between them the better for accurate judgment as those who have had experience with different photometric screens well know.

CONCLUSION.

The figures here presented confirm previous knowledge that the brightness contrasts or differences within the field of vision with the undiffused light of modern artificial illuminants are much greater than those to which we are ordinarily similarly exposed for considerable periods with natural light.

Indirect artificial lighting is being commonly carried out with brightness differences in the field of view approximating north exposure daylight. The distribution of the brightness within the field of vision in the two cases is however different.

Printing and writing do not present the contrasts with the paper that is popularly supposed. Writing ink makes a less glazed mark than either black or indelible pencil, and is therefore preferable for comfort and ease of reading.

THE FIREFLY AND OTHER LUMINOUS ORGANISMS.*

BY F. ALEX. MCDERMOTT.

Synopsis: This paper embraces a brief review of the present state of our knowledge of the production of light by living organisms, with special emphasis on the physical properties of the emitted light, and the chemical processes involved in its production. Although there still remain many points for future workers to clear up, it has been shown that the firefly expends all of the energy used in light production within the range of the visible spectrum, the maximum of the energy distribution curve falling near those wave-lengths having the greatest illuminating power. Infra-red, ultra-violet, and penetrating radiations are absent. The chemical processes involved are probably those of the oxidation of some physiologic substance; there is some evidence that this substance may be a nucleo-albumin. The watts-per-candle efficiency is in the neighborhood of 0.054 watts per candle. The material may be dried out of contact with the air, without losing its power to produce light when moistened.

The power to produce light is quite widely distributed among animal forms, and much less widely among plant forms. The fireflies do not appear to produce the substance as needed, but start adult life with a limited amount. The organs for the production of light vary greatly in structure in different groups of animals, and in some cases show very intricate structures. In the fireflies, the light is a secondary sexual character; in other forms the usefulness varies.

The subject of this paper is one which has interested me greatly during the past few years, and one which is of wide scientific interest because of its relations to the problems of physics, chemistry, biology, and other fields of knowledge. In spite of the very considerable amount of work which has been done upon it, the phenomenon of the production of light by living organisms is still in many ways a mystery, and the popular conceptions concerning it are usually very far from the point.

HISTORICAL.

But little need be said here regarding the development of our knowledge regarding the luminous organisms. Various authors from the time of Aristotle have mentioned some phase of the

* A paper presented at a meeting of the Pittsburgh Section of the Illuminating Engineering Society, April 17, 1914.

subject; the scientific literature relating to it is quite vast, and the card index covering this literature which I have attempted to prepare now contains considerably over 1,200 cards, and the list is still growing. Among the prominent names which may be found in this index are those of Boyle, Spallanzani, Humphrey Davy, Faraday, Darwin, Pasteur, Pflüger, the late S. P. Langley, and a host of others not so widely known.

It is only within comparatively recent years, however, that any considerable advances have been made in our knowledge of the subject, and there still remain many points for future workers to clear up.

DISTRIBUTION IN NATURE.

The expressions of vital energy as heat, sound and motion, are so generally known that the ordinary observer pays but little attention to them; the production of electricity is so rare a property of living tissue that it is not likely to be encountered by more than a very small fraction of mankind. Between these two extremes stand the forms which have the power to produce light—sufficiently widely distributed among the creatures of the earth to have been seen by the majority of mankind, and yet sufficiently rare to excite the amazement and curiosity even of those who may daily observe them. There are representatives of the class of luminous organisms in both the plant and animal kingdoms. In the plant kingdom the luminous species are confined to a few bacteria and fungi; the reported cases of luminosity in higher plants are either doubtful or of a different nature. In the animal kingdom, however, the property is much more wide spread. Starting with the lowest forms, the unicellular protozoa, one finds the tiny Noctiluca, to whose presence in vast numbers is due the so-called phosphorescent sea; a number of other marine protozoa are luminous, and above these are luminous members in almost every plane of development up to and including the fishes. Among commonly known forms which have luminous species are the insects, fishes, centipedes, crustacea, cuttle-fish, star-fish, and worms. To many people the various species of fireflies and glow-worms are the best known luminous animals. Most of my own work has been with these insects, and what I have to say relates principally to them.

PHYSICAL PROPERTIES OF THE LIGHT.

To this Society the most interesting points in this field are those related to the chemical processes by which the light is produced, and the physical properties of the light itself.

With our ordinary light sources, in which the light is produced by heating some refractory body to incandescence, only a relatively small amount of the total energy supplied is radiated within the limits of the visible spectrum, the remainder being expended in infra-red and ultra-violet radiation, which is useless for illumination. By the use of substances showing selective radiation, as is done in the Welsbach mantle, the mercury arc, and the flame arc, we have been able to increase the proportion of energy expended in radiation within the limits of the visible spectrum, but as yet we have not secured a source of light showing selective radiation entirely confined to the visible spectrum. This the firefly has accomplished.

Several investigators have subjected the light from various species of luminous organisms to spectrum analysis, and for the most part the results have been in close agreement. The first really extensive work was the bolometric study made by Langley and Very in 1890, on the Cuban cucuyo, in the Allegheny Observatory. They found that the light of this insect gave a continuous spectrum lying between 468 and 640$\mu\mu$, with a maximum at 530μ, and giving no hint of continuation in the infra-red or ultra-violet. They concluded that the light had an illuminating efficiency of practically 100 per cent. In 1908-9, Drs. Ives and Coblentz, in the United States Bureau of Standards, submitted the light of the common firefly of the vicinity of Washington, D. C., to spectrophotographic analysis, and found it to consist of a structureless, unsymmetrical band, extending from 500$\mu\mu$ to 670$\mu\mu$, with a maximum at 570$\mu\mu$. Both the entire band and the maximum are thus shifted toward the red as compared with the light of the cucuyo. They estimated the illuminating efficiency of the light as about 96.5 per cent.; this figure has since been reduced to about 90 per cent. by later studies by Dr. Coblentz. As Ives and Coblentz remark, the firefly has carried the matter of efficiency in light-production too far for human needs, as such a light would, on account of its color, be even less de-

sirable for general illumination than the mercury-vapor arc. The light emitted by the various species of firefly and glow-worms is usually stated to be yellowish-green, green, or bluish-green; the light of the luminous bacteria is similar. This is easily seen to be due to the distribution of energy in the spectrum, the maximum usually falling in the yellowish-green section, and being very sharp, the curve falling off rapidly towards the ends of the spectrum. However, all luminous creatures do not emit light of the same color. Dr. Coblentz has studied spectrophotographically the light from several species of fireflies from the neighborhood of Washington, and has shown that while the spectra are similar, there are differences between them. One group of glow-worms give a reddish light, in which the unusual tone does not appear to be due to absorption; and some marine forms, notably one deep-sea cephalopod, give lights of various colors. Curves showing the energy distribution in the various spectra may be found in the papers by Langley and Very, Ives and Coblentz, and Coblentz; for comparisons of the spectral ranges, see the above papers, and one by the writer in the Smithsonian Report for 1911; also either Mangold or Molisch.

Further studies by Ives and Coblentz have failed to show any evidence of ultra-violet or infra-red radiation. One observer (Forsyth) claims to have found ultra-violet rays in the light from one species of bacterium; but the result is at variance with other studies on this point and requires confirmation. Dr. Coblentz's recent work shows that the luminous portions of the firefly, whether giving light or not, are at a very slightly higher temperature than the rest of the insect's body.

Coblentz has studied the transmissivity of the chitin covering the luminous apparatus of the firefly, for wave-lengths not included in its spectrum, and finds that were these wave-lengths generated, they would not, for the most part, be absorbed by the chitin.

Ives and Coblentz estimated the watts-per-candle efficiency of the firefly at about 0.02; Ives and myself have obtained 0.054, using a different basis of calculation. This is about ten times as good as the nitrogen-filled tungsten lamp. Ives and Jordan give the intrinsic brightness of the glow-worm as 0.0046 candle-

power per cubic centimeter. (Their glow-worm was the young of the firefly.

A number of observers have stated that the light of the firefly, luminous bacteria, etc., shows penetrating effects similar to those produced by X-rays and radium. This phenomenon, which was so puzzling for a while, has been found to be due to traces of peroxid of hydrogen, or some other volatile peroxid, produced either by the organisms themselves or the medium upon which they grow, and which affect the photographic plate very strongly. It is of interest to note that cultures of luminous bacteria in a state of activity do not affect a charged electroscope, nor does the firefly affect the fluorescope.

CHEMISTRY OF THE LUMINOUS PROCESS.

With the progress of science in general, various theories have been advanced from time to time to account for the phenomena presented by luminous organisms. The first theory was that the light was due to the presence of free phosphorus; this theory is really without any sound scientific basis. Another view assumed phosphine to be the active material, and this theory was held by Lavoisier and by Humphrey Davy; it also has fallen, owing mainly to the fact that no phosphine or similar compounds can be found. The idea that substances similar to the phosphorescent alkaline earth sulphides might be present has also been advanced and abandoned for lack of proof. It may be said in passing that the light of living forms has but little in common with that of the so-called phosphorescent sulphides.

At the present time there is but little doubt that the light is produced by the oxidation of some complex physiologic product by means of the oxygen of the air. This specific substance would doubtless not prove to be the same in all luminous species. No one has so far succeeded in isolating the substance in the pure condition, and our knowledge of the chemical structure is necessarily limited. It seems probable, however, that it belongs to the class of biologic substances known as nucleo-proteins, possibly a nucleo-albumin. The presence of fatty substances combined or closely associated with the nucleo-protein is also probable. The evidence for these statements is scattered, and rather meager at best, and to give it here would take me rather too

far into the domain of biologic chemistry. The question of the intimate mechanism of the luminous process is closely related to the general problems of respiration and the oxygen requirement of the living cell, and also with the problems in the field of autoxidation.

In practically all cases so far studied, three factors appear to be necessary for the production of light; water, oxygen, and the substance oxidized. The role of water is of considerable interest. Over 100 years ago it was found that if the luminous tissues of certain forms be dried, they could be made to give light again, simply by moistening in the air. This observation has been applied to a considerable number of organisms, and in the series of experiments made by Prof. J. H. Kastle and myself, it was found that if the luminous tissue of the firefly be dried in vacuum over sulfuric acid and sealed out of contact with the air, it can be kept for over two years without any apparent diminution of its activity. After moistening once, if the tissue be carefully dried, it may be made to give light a second or even a third time. While dry, the material may be heated to 100° C. without losing its activity, although a temperature sufficient to coagulate albumin destroys the activity of the moist tissue. Cultures of luminous bacteria may be dried and give similar results. Liquid air does not destroy the activity of either the fresh or dried tissue, even when the latter are ground in it. Luminous bacteria may be exposed to liquid air, or even liquid hydrogen, for a short time, without losing their power to grow and produce light upon return to normal temperatures; however, prolonged exposure, or grinding at the low temperature served to prevent growth and luminescence upon restoration of normal conditions.

In its general conduct the tissue shows some similarity to the ferments and enzymes, and this brings us to Dubois' enzyme theory of light production. This investigator thinks that the light is due to the oxidation of a nucleo-albumin by the oxygen of the air, through the action of an oxidizing enzyme or soluble ferment. It cannot be said that the theory is definitely established, but it certainly has much of interest in it. The question as to whether the process is really an oxidation or not was argued to and fro until recent years, but there is at present but little valid

evidence opposed to the oxidation theory. It is of interest to note in this connection that if, when experimenting with the dry material, a hydrogen peroxid solution, instead of water, is used to moisten it, the resulting light will be quite a little brighter than with water. Dubois also found that solutions of certain oxidizing agents could replace his oxidizing enzyme solution.

The effects of various physical and chemical agents on the tissues are of interest, and much of the work that has been done on the problem has been along this line. In general it may be stated that the tissues are very irritable, and that light emission is produced in the resting tissues by mechanical stimulation, heat within certain limits, and electrical stimuli. The action is usually the same whether the living insect or the freshly detached luminous tissue be used. Chemical irritants and poisons are very active in producing light emission; practically all poisons, even though they kill the creatures, cause light emission first,—that is, the first effect is a stimulation, as in the action of poisons on other physiologic functions. The vapors of ordinary alcohol, wood alcohol, chloroform, carbon tetrachlorid and carbon bisulphide are especially active when applied in the presence of air to the freshly detached tissue of the firefly, causing flashes of light similar to the normal coruscations of the insects, while most other stimuli cause a continuous and sometimes rather faint glow. Oxygen, either alone or when charged with ozone, though more active than air, does not act as strongly as might be expected from the statements made above as to the process being an oxidation. Nitrous oxid is about as active as oxygen.

The one exception to the above stimulant action of poisons is sulfur dioxid. In the great majority of the cases where this gas has been used, an immediate and permanent destruction of the light-producing power takes place, only occasionally a faint light-emission preceding the poisonous action. Iodin cyanid, bromin, and a few other compounds act similarly, but less powerfully.

In its conduct toward chemical stimulants the dried tissue, after moistening, acts in practically the same way as the fresh tissue.

When heated above a certain temperature, the fresh, moist

tissue loses its power to produce light. This temperature varies with the species, but evidently represents the point at which the albumin coagulates.

Many of the luminous bacteria are marine in origin, and will not produce light in the absence of sodium chlorid or some similar compound in the same concentration as found in sea-water —about three per cent. These organisms will grow and produce light in extremely simple media; a three per cent. solution of common salt containing one per cent. of asparagin (alpha-amino-succinamidic acid, $COOH\text{-}CHNH_2\text{-}CH_2\text{-}CONH_2$) will serve in some cases.

Coblentz and Lund both mention the apparent exhaustion of the luminous material of the firefly; apparently a supply of this substance is not continually formed during the life of the insect, but the creature begins its adult life with a limited capital of photogenic substance.

STRUCTURE OF THE LUMINOUS ORGANS.

Many of the lower unicellular forms do not appear to possess definite organs for the production of light, the property being a general one of the entire cell. Still higher protozoa show a localization of the light-producing power in certain points on the cell; this is the case in Noctiluca, the organism causing the "phosphorescent" sea. With increasing complexity of the organism as a whole, the luminous apparatus become more and more complex, reaching its maximum in the fireflies and the fishes. In some creatures, the luminous organs are glands which excrete the photogenic substance directly into the air or water, where it is oxidized and gives light; in others the substance is burned within the organism. In this latter class belong the fireflies.

The luminous tissue of the firefly consists chiefly of two layers, the inner one being white and opaque, and the outer yellowish and translucent. Both layers are penetrated by a large number of trachea (air passages) which are indistinguishable in structure from the breathing trachea, and which unite with the latter at the spiracles (breathing orifices). These air tubes pass without branching through the inner layer outwards into the outer yel-

lowish layer, where they throw off numbers of fine capillaries, these latter forming a close network through the tissue.

The white layer appears to consist of compounds of or related to uric acid; the yellow layer apparently consists of the photogenic substance with its supporting tissue. According to the work of Lund, the luminous process is accomplished with the deposition of the white material from the yellow, the chemical tests indicating the breaking down of nucleic acids. Lund also studied the blackening of the luminous tissue by osmic acid, and concluded that a substance having the nature of a reductase (reducing enzyme) was present.

In certain fish, crustaceans, cephalopods, etc., one finds a very remarkable form of luminous organ. It is only within comparatively recent time that man has learned to direct a beam of light forward by means of lenses and reflectors, but the animals just mentioned have been doing so doubtless for geologic ages. They possess photogenic organs having a "bull's-eye" or "searchlight" structure, consisting of a reflecting layer,—not infrequently having an approximately parabolic longitudinal section,—with a light-producing body located at the focus, and provided with a lens. For many years the true character of these organs was not known, and they were refered to as auxiliary eyes, but in a number of cases they have been seen producing light, establishing their function beyond question. Some of these structures are very complex, the advantages of the arrangement being, from our point of view, a little hard to understand. In the marine forms the oxygen necessary for the luminous process is supplied through a net-work of blood vessels similar to the network of air-tubes in the firefly.

PURPOSE OF THE LUMINOUS FUNCTION.

The luminous organisms present many interesting problems in phylogeny, but we need, and indeed can say but little about this phase beyond the fact that the power to produce light appears to be a very primitive property of living cells, and that the existing forms present some remarkable instances of convergence.

Almost the first question that a good many people will ask regarding the firefly is "What good is the light to the insect itself?" In the fireflies, the light-producing power serves to

bring the sexes together for mating, and is essential to the maintenance of the species. The same probably holds for most luminous insects, and probably for other forms to some extent. There are known cases, however, where the utility of the power appears to be entirely that of luring prey, or discouraging the attacks of enemies. In many of the simpler forms no adequate explanation is apparent at present.

It is of interest to note that the females of the fireflies use two forms of light-emission which may be distinguished as "direct" and "indirect" illumination. Our ordinary species use the indirect method, that is, the luminous apparatus is on the ventral side, and the insect clings to the grass or earth with the luminous apparatus directed downward, and when she flashes, the male sees not the luminous apparatus itself, but the reflection of the flash on the ground or foliage. Other species, however, have the luminous apparatus of the female on the dorsal side, or even, in one species, the insect curls the abdomen over the back, so as to expose the luminous apparatus upward—the direct system.

PRACTICAL APPLICATION.

It must be said that at this time there is little upon which to base a hope of the future practical application of physiologic light. It has been suggested that cultures of some of the more brightly luminous bacteria light be utilized as illuminants in coal mines, powder magazines, etc., but the cost would of course be prohibitive at present. We do not know the nature and constitution of the photogenic material, and even if we did, the synthesis of the material in the laboratory or commercially would probably be an enormously expensive process. A large number of chemical reactions which produce light are known—mainly oxidations taking place in an alkalin solution. However, the light is in most cases quite feeble, and very expensive in all. (See papers by the writer in *Scientific American,* Sept. 14, 1912, p. 225, and *Journ. Amer. Chem. Soc.,* 1913, vol. 35, p. 824.) Of course during my studies I have been accused of intending to run the electric lamp makers and illuminating gas manufacturers out of business, but so far as I can see, the production of artificial firefly light will not interfere with the present methods of illumination—at least not for a long time to come.

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DISCUSSION.

PROF. ALEXANDER SILVERMAN: Professor McDermott has presented most clearly the results of researches in a field rarely entered by the chemist. Anyone, not a specialist, reluctantly ventures to discuss such a subject, and yet there are points of interest which might be mentioned though they may have no direct bearing on phenomena recorded in the paper.

Certain chemical substances cause specific rotation of light rays passed through them. This can be calculated, but observed data may differ from the theoretical. A number of investigators have written on the subject and a brief consideration of results may be of interest here. The molecular rotation of aniline as calculated from benzene, nitrogen and hydrogen is 12.25; the observed rotation is 16.07 showing the magneto-optical anomaly of plus 3.82. In some cases the anomaly is negative, as for nitrobenzene, minus 2.15. With negative magneto-optical anomaly no luminescence is observed, but luminescence increases as the positive anomaly increases. In aniline, already mentioned, luminescence is strong; in dimethyl aniline, anomaly plus 8.59, intense; and in dimethyl p. phenylene diamine, anomaly plus 10.97, very intense.

In a conversation held with Professor McDermott since his paper was read, he mentioned that fluorescent extracts of luminous substances (from organisms) were prepared but that no concordant results had been obtained. Results, may, however, yet show a relationship between data such as above given and compounds isolated from living organisms.

THE PHYSIOLOGY OF THE EYE AND ITS RELATION TO RAILWAY SIGNALING.*

BY NELSON M. BLACK, M. D., MILWAUKEE, WIS.

Synopsis: In the following paper the anatomy of the eye and physiology of the visual act for form are described together with various factors interfering with clear vision. The relation of the size of position signals to the visual angle is mentioned. The physiology of color vision is described and the factors which influence the perception of color are included with a description of the spectroscopic qualities of the rays in solar light. The spectral and photometric standards of the Railway Signal Association are given. Sub-normal color perception is considered together with the theories as to its cause and the adequacy of various tests for its detection. Conditions in railway service interfering with the visability of signals are also described.

In the day time railway signals require of certain centers of the brain, through the medium of the visual apparatus, the recognition of the position (as a result of the light reflected from it) of a flat surface of certain dimensions; or, on some roads, the determination of the color reflected from the surface of some colored material of specified dimensions, exposed approximately at right angles to the line of vision. In other words those centers of the brain which appreciate form sense are stimulated in the first instance and in the latter the centers having to do with form sense and color sense are jointly stimulated.

At night the physiological stimulus is different in that the receptive portion of the visual apparatus is excited by the direct rays from the visible spectrum of some illuminant, as well as those rays passing through some transparent, filtering or absorbing medium which gives to the incident rays certain characteristics which are interpreted by the brain centers controlling color sensations as color.

Generally speaking the visual act may be considered as that

* A paper read at a meeting of the Chicago section of the Illuminating Engineering Society, April 10, 1914.

process whereby luminosity, form or color is recognized by the visual apparatus.

The anterior portion of the eye composed of the cornea, iris and lens concern us only as factors in bringing to a focus the incident light rays upon the receptive portion of the visual apparatus known as the retina. This coat of the eye is a complex nervous structure, the chief constituents of which are known as the rods and cones which are submerged in a certain photochemical substance known as the visual purple. To and from the rods and cones come and go nerve fibers which put the retinal elements in communication with lower and higher levels of the brain, the large trunk lines leading from the eyes being the optic nerves.

Approximately at the center of the retina is a region known as the macula and within this region is a small area known as the fovea in which vision is sharpest. How the visual act is accomplished is not absolutely proved, but the theory advanced by Edridge Green appeals as being the most rational:

> The cones of the retina are insensitive to light, but sensitive to chemical changes in the visual purple. Light falling on the retina liberates the visual purple from the rods and it is diffused into the fovea and other parts of the rod and cone layer of the retina. The decomposition of the visual purple by the light chemically stimulates the ends of the cones (probably through the electricity which is produced), and a visual impulse is set up which is conveyed through the optic nerve fibers to the brain. . . . . The visual impulses caused by the different rays of light differ in wave-length. Then in the impulse itself we have the physiologic basis of the sensation of light, and in the quality of the impulse the physiologic basis of a sensation of color.

The rapidity of decomposition of the visual purple depends, to a great extent, upon three factors: the amount of light gaining entrance into the eye, the intensity of the light and its color. The greater the amount and intensity of the light reaching the retina the more rapid the decomposition of the visual purple. With colored light the greatest activity in producing decomposition lies in about the middle portion of the visible spectrum, the greenish yellow being the most active, yellow next, blue next, violet next and red least active.

A light wave starts on its journey through the ether reflected from some surface or a luminous object which is its source. The first step

towards its becoming a visual impulse is taken when it decomposes the photo-chemical substances of the retina, thus setting up vibrations in the extreme periphery of the end organs of this membrane. The initial psychical step is taken when it reaches its first stopping place in the brain cortex.

The excitation received by the retinal substances and structures is conveyed by fibers of the optic nerve back to centers at the base of the brain, and either directly or by new relays of fibers to the visual cortex. Definite portions of the retina are related to equally definite portions of the visual center which first receive the projected retinal excitations. The result in the cortical centers first receiving the impulses is a visual sensation or percept. Up to this point, however, an idea of the object perceived is not obtained. In order that this shall come to pass the cortical excitation which has been invoked must be transmitted to the cellular elements of another region of the brain surface; in other words, from a simple sensory or percept center to a memory center. A memorial image is deposited in the center placed at some distance from the cell or cell-group in which the excitation is received.

FORM VISION.

The ability of the normal eye to distinguish the form of an object depends upon (1) the size of the image received upon the retina; (2) the amount of light reflected from it; (3) the contrast with the background. The results obtained from the examination of a great many individuals with good sight have shown that with the average eye the form of an object can be recognized if the angle subtended by it at the retina equals 5 minutes or, if parts of the object such as a letter, which subtends a 5 minute angle, are wide enough to subtend a 1-minute angle.

The amount of light reflected from an object must be sufficient to act upon the photo-chemical visual substance and cause stimulation of the nerve endings. The coefficient of reflection between an object viewed and the background must differ sufficiently to make a contrast; otherwise the object will be invisible.

It must be understood that very many persons have vision much better than that which is considered normal, or an eye whose visual angle is 5 minutes. Many individuals can distinguish objects which only subtend a 3-minute angle. The same difference is true in individuals with respect to the light sense, but these are individual peculiarities and not characteristic of any particular race.

The determination of the average visual angle has resulted

in the adoption of letters for the purpose of testing vision which as a whole subtend a 5-minute angle and whose strokes subtend a 1-minute angle at the distance they are used.

Applying the above data to railway signals,—by some strange coincidence and to the best of my knowledge not the result of a mathematical determination of the visual angle of the eye, the average semaphore blade in use in the United States practically subtends at ½ mile a 5-minute angle in its long dimension and a 1-minute angle in width. Thus anyone with average normal vision should have no trouble in determining the position of the semaphore blade at ½ mile (0.67 km.) under average weather conditions and good backgrounds.

The indication of a signal must be recognized at a distance not much less than a half mile in order to control the movements of many of the limited trains at the speed they are driven at the present day.

There are various factors which interfere with visual acuity or form vision which exist in the dioptric system of the visual apparatus, such as far-sightedness, near-sightedness and astigmatism. These defects are anatomical in character. Far-sightedness or hyperopia is a condition in which the eye-ball is too short for the cornea and lens to bring diverging or parallel incident rays to a focus upon the retina, resulting in a blurred retinal image. Near-sightedness or myopia is a state in which the eye-ball is too long and the incident parallel or converging rays are brought to a focus in front of the retina, producing a blurred retinal image. When the cornea or lens is not the true segment of a sphere, the result is astigmatism; in other words, the curvature of the cornea is greater in the vertical meridian than it is in the horizontal, resulting in an irregularly shaped retinal image. This condition may be associated with either hyperopia or myopia.

Fortunately these anatomical defects may be corrected by the use of convex, concave or cylindrical lenses, and lowered vision when due to the above defects alone may easily be brought up to the normal or standard. If the visual defects lie within the retina or within the conducting or receiving portion of the visual

apparatus they are in a vast majority of instances beyond human aid.

Railway officials in conjunction with ophthalmic surgeons have adopted minimum standards of visual acuity for different classes of employees and require all to pass an entrance examination and to submit to re-examinations at stated periods. The minimum standard for entrance into service for enginemen and firemen is normal or standard vision known as 20/20 vision (or the ability to read letters which subtend a 5-minute angle at 20 feet, (6.096 m.) with both eyes and not less than 20/30 vision with either eye alone. The effect of training and being educated to observe and interpret what one sees is evidenced by the remarkable vision of some old enginemen whose vision by card test was found to be reduced to 1/10 and 1/20 of standard or normal. These men were placed upon engines and run towards signals and they could give the indications at from 1,600 feet to 2,500 feet (487.68 m. to 762.0 m.).

The cause of reduction in form vision may be the result of inflammation or injury of the anterior portion of the eye or cornea with resulting scars, inflammation of the iris with deposits upon the anterior surface of the lens which obscure vision, the opacification of the lens itself or cataract, diseased condition of the general system or eye resulting in opacities in the vitreous and various diseases of and hemorrhages into the retina, in such conditions the vision can not be improved with glasses. Vision is also reduced in many instances with on-coming age, the result of loss of the power of accommodation due to hardening of the lens substance. Such loss of vision can be as a rule brought to normal with lenses overcoming the loss of accommodative power The diminished visual acuity in the above mentioned cases was due to such cause and the men wearing their glasses could tell the signal indications without any trouble at the maximum distance tested or one mile.

COLOR SIGNALS.

It is the generally accepted theory that the sensations of light and color are the result of vibrations from a luminous body transmitted through an assumed medium (the ether) to the retina. Luminous bodies usually give rise to vibrations or waves

of many different lengths, a small proportion of which are visible at the fovea of the retina as a single composite color, unless refracted or filtered by some interposed medium or reflected from some non-luminous body which absorbs a portion of the incident rays.

If the vibrations or waves in a composite ray of light are balanced in certain proportions pure white light results, which is a sensation of maximal light intensity devoid of color.

If a ray of pure white light is refracted or broken into its component parts by a prism and a screen be interposed in the path of the beam, the waves of different lengths are thrown at different angles upon it, in a band extending through the entire range of color from red to violet. The following table shows the order of the spectrum colors, the lengths of the corresponding waves, and the number of vibrations per second:

Color	Fraunhofer lines	Wave lengths in ten millionths of a millimeter	No. vibrations per second in million millions	Relative intensity in solar spectrum	Relative intensity in kerosene (yellow area) flame spectrum	Relative power of saturation (approximate)
Extreme red	A	7594		5	1	2.50
Red	B	6867	450	6	16.5	2.15
Red	C	6562	472	24	48	1.90
Yellow	D	5892	526	98	99	1.00
Green	E	5269	589	47	19	1.10
Green	b	5183		31	10	1.00
Blue-green	F	4861	640	16	4.25	0.95
Indigo-blue	G	4307	722	2.25	1	1.65
Violet	H	3968	790	1.5	0.5	3.25

The Fraunhofer lines are constant black lines which are found in the solar spectrum. The more prominent ones are lettered and used to indicate the most saturated portions of the spectrum with regard to the spectral colors.

The longest wave-length affecting the retina gives rise to a sensation of red, then in order follow orange, yellow, green, blue and violet.

For every visible color in the spectrum there is a corresponding complementary color which when mixed with it produces white light.

By mixing any two hues which are not complementary to each other a hue is produced which is intermediate between the two.

When two colors are brought into close proximity each changes the appearance of the other. For instance, if orange and yellow lights are shown side by side the orange will appear much redder than it would alone.

The visual act required in the recognition of signals, which depend upon color, does not differ from that required with the form sense, except that the terminal memory centers are different and the nerve fibers conducting the impulse may be different ones.

The average normal eye can differentiate 6 distinct colors in the visible spectrum. The ability to do so depends upon three properties or constants, (1) the hue; (2) the saturation and (3) the intensity of the color.

By the term hue, is meant the kind of color, *i. e.*, red, green, blue, etc.

The term saturation applied to color refers "to the degree of admixture with white, the saturation diminishing as the amount of white is increased. The highest degree of saturation belongs to a given color when in the state of great purity." Pink or pale blue may be cited as instances of low saturation; scarlet or Prussian blue are instances of high saturation.

The term intensity applies to the brightness, the luminosity of a color. When speaking of transmitted light it signifies illuminating power as well; in the case of objects seen by reflected light such as the disk of the Hall signal, silk or a flower it stands for mere brightness.

The discussion in this portion of the paper unless otherwise stated will refer only to transmitted light.

Applying the color constants to railway signals—the hue of spectral colors depends physically upon the wave-length of the etherial vibrations in each ray, so, the terms hue and wave-length are practically synonymous when applied to spectral colors. However, in signal practise and in nature we very rarely have to deal with isolated spectral colors. The colors used in railway signals are made up of several rays or groups of rays and the color sensation obtained and perceived by the visual apparatus is the result of comparing the dominant wave-length of such group of rays with the nearest spectral color of definite wave-length.

The hue and saturation of the rays of light passing through any

piece of glass are simply the combined effect of the various light waves transmitted and depend upon, (1) the quantity of light of each wave-length received from the source of illumination; (2) the quantity of different wave-lengths transmitted by the glass; (3) the power of saturation of each wave-length transmitted.

The intensity of any signal depends upon: (1) the absolute candle-power of the source of illumination; (2) the quantity of light transmitted by the glass.

The following table gives the spectro-photometric analysis of roundels of the various colors of medium intensity as specified by the Railway Signal Association. The letters indicate the Fraunhofer lines of the spectrum, and the figures show percentages of light transmission at the different points. Roundels of medium intensity should transmit light as nearly as possible of this composition, a reasonable variation being allowed for light in dark limits.

	A	a	B	C	D	E	b	F	G	H
Red	60	65	70	72	0	0	0	0	0	0
Green	0	0	0	0	4	27	40	45	25	0
Yellow	0	38	50	43	41	12	9	3	0	0
Blue	0	0	0	0	3	4	6	24	40	46
Purple	0	42	42	0	0	0	0	2	43	42
Lunar white	0	62	49	17	15	25	38	65	74	0

Red shall be of such quality that all yellow rays of light are absorbed, the spectrum being either red, or red and orange. The photometric value shall be, light one hundred and thirty (130), standard one hundred (100), dark seventy (70).

Green shall be of the color known as admiralty green, having a slightly bluish tint. The spectrum shall show very little yellow, being a full green with some blue. The photometric value shall be, light one hundred and twenty-five (125), standard one hundred (100), dark seventy-five (75).

Yellow shall give a spectrum showing a full yellow band, most of the red and slightly of the green. The photometric value shall be, light one hundred and twenty (120), standard one hundred (100), dark eighty (80).

Blue shall give a spectrum having a full blue band, with a narrow band of green. The photometric value shall be, light one hundred and twenty-five (125), standard one hundred (100), dark seventy-five (75).

Purple shall give a spectrum showing a considerable proportion of both red and blue. The photometric value shall be, light one hundred and twenty-five (125), standard one hundred (100), dark seventy-five (75).

Lunar white shall show a maximum of absorption for the yellow. The photometric value shall be, light one hundred and twenty (120), standard one hundred (100), dark eighty (80).

The colors transmitted by glass meeting the above specifications are not mixed with white so are in a state of greatest saturation.

The quantity of light of each wave-length transmitted from the source of illumination by each colored glass is shown in the table. The quantity of light transmitted by the red and green roundels is from 25 per cent. to 35 per cent. of the original source, illumination of 40 to 70 candle-power, obtained from the ordinary semaphore lantern, which is dependent upon the type and size of the burner, the lens and focal adjustment of flame, reflector, condition of lamps, etc., such specified red, green and yellow glass give an approximate range of three miles in clear weather.

Thus railway employees with normal color perception should have no difficulty in recognizing the color of signals under average weather conditions at a sufficient distance within which to control limited trains.

DAY COLOR SIGNALS.

The size of the colored disks used in the Hall or banjo signals unfortunately does not happen to approximate the physiological optical conditions, to anywhere near the degree the semaphore blade does. Peculiar as it may seem from the fact that red light is the least active in decomposing the visual purple in order that reflected light from a red and green surface may be perceived with equal clearness at the same distance the green surface "must either be 5 times more powerfully illuminated than the red or given 5 times more exposed superficial area." Such being the case the relation between the size of the green and red disks of the Hall signals is not proportioned for equal visibility and neither is the incidental light different although the index of reflection from the green disk is probably greater than from the red which undoubtedly tends to equalize the visibility.

SUB-NORMAL COLOR PERCEPTION.

It has been known since 1777 that there exists considerable variation in the ability of different individuals to recognize certain colors, but it was not until 1855 that Wilson, an English

scientist, pointed out the dangers of defective color perception from a practical standpoint. Little attention was paid to the work until Holmgren following in the footsteps of Wilson and recognizing the cause of a terrible railroad wreck in Sweden to be the result of color blindness set about making a study of this ocular condition and was one of the first to devise practical methods of detecting the defects.

A discussion of the theories of color blindness can not be gone into the space allotted in this paper; a brief summary is therefore given.

The Young-Helmholtz theory (first proposed by Thomas Young in 1807, and subsequently modified by Helmholtz) assumes that the terminal fibrils of the retina are arranged in three distinct sets for the reception of the three primary colors—red, green, and violet. These groups correspond to the three colors, and acting simultaneously induce the sensation of white. Red light entering the eye affects to the greatest extent the group of filaments known as the red sensitive elements, and also affects the others to a slight degree. In like manner green and violet are perceived by their corresponding sensitive elements. The absence or imperfect development of the retinal area set aside for one of these primary colors will cause this color to be seen as if composed of the two remaining colors, thus giving rise to color blindness corresponding to the deficient color elements.

Hering theory: This theory assumes the existence of three separate visual substances in the retina. Each of these substances is decomposed by the action of light and is renewed when the eye is permitted to rest in the dark. Both the decomposition and the renewal of the visual substances result in the production of color sensation.

The Hering visual substances are divided into three sets of two each, *i. e.,* (1) white-black substance; (2) red-green substance; (3) blue-yellow substance.

When the black-white substance is decomposed the sensation of white is produced. When this substance is renewed the sensation of darkness results.

When the red-green substance is decomposed the sensation of red is produced, and when it is renewed the sensation of green results.

Whn the yellow-blue substance is decomposed the sensation of yellow is produced; when it is renewed the sensation of blue results.

Red light produces the sensation of red by decomposing the red-green substance. Orange light produces the sensation of orange by decomposing both the red-green and the yellow-blue substances. Yellow light produces a sensation of yellow by decomposing the yellow-blue substance, the red-green being then in equilibrium. Green light produces the sensation of green by the renewal of the red-green substance, the yellow-

blue being now in equilibrium. Blue light produces the sensation of blue by the renewal of the yellow-blue substance. Violet light does the same, though to a less degree.

The latest and probably the most comprehensive theory is that of Edridge Green, which was described under the heading of form vision.

There are two forms of color blindness one a congenital defect which can not be educated or remedied, the other an acquired form produced by tobacco or alcohol poisoning or the result of some acquired disease such as syphilis or of some brain injury or disease.

The principal types of congenital color abnormalties are usually described under the headings of *total* and *partial color-blindness.*

The portion of the visual apparatus responsible for congenital color blindness is an unsettled question and while many scientists are of the opinion that it is due to defective development of the portion of the brain which has the function of the perception of color, we must not exclude defects in any portion of the retino-cerebral apparatus. In the acquired cases the portion of the visual apparatus affected can usually be determined.

Sub-normal color perception is found in about 3½ to 4 per cent. of males and in about 0.08 per cent. of females.

There are two separate and distinct classes of color blindness, although they both may be present in the same individual. In the first class there is diminished light perception as well as loss of color. In the second class there is normal light perception, but a colored defect exists.

The individual having a diminished light perception is in the same condition as one having normal color perception viewing a spectrum in which certain rays are blotted out entirely or reduced in intensity. These cases show a shortening of the violet or red end of the spectrum. Those having defects of color perception perceive the luminosity effect of the entire spectrum but see a less number of colors.

Sub-normal color perception which is most dangerous in marine and railway service is found in the *dichromics,* who are able to distinguish but two colors in the spectrum and the *trichromics* who are able to distinguish but three colors. The two colors seen by the dichromic are red and violet with a neutral point

located about midway in the green of the normal sighted. The red, orange, yellow and half the green are seen as red becoming less and less saturated as the neutral point is approached, this neutral region becoming more and more saturated with violet towards the violet end of the spectrum. In uncomplicated cases the luminosity curve may equal that of the normal. There may be shortening of the spectrum at either the red or violet end. The chief difficulty with the trichromic, who see red, green and violet in the spectrum, is in distinguishing yellows and blues, a yellow adjacent to a green will be called red and the same yellow next to a red will be called green.

It is noticeable that an individual with sub-normal color perception is (a) much more dependent upon the luminosity of the color than one with normal color vision; *i. e.*, a stronger stimulus is required; (b) fatigued more readily with colors; (c) more sensitive to simultaneous contrast; (d) requires a color object which subtends a larger angle; (e) has a poorer memory for colors.

Unfortunately congenital defects in color vision can not be remedied by any means known at the present time; consequently tests have been devised for the purpose of eliminating those applying for positions in which the recognition of color is of practical importance such as in marine and railway service.

The requirements of a color blind test should be such as to: (a) show *absolutely* that the individuals rejected are dangerous; (b) make it impossible for the examinee to be coached through it; (c) be carried out as rapidly as is compatible with absolute efficiency.

Persons to be excluded are: (a) those who see three or less colors in the spectrum; (b) those who have the red end of the spectrum shortened to such an extent that they can not distinguish a standard red signal light at two miles, although they may be able to perceive more than three colors in the spectrum; (c) those unable to distinguish between red, green and white lights when the retinal image is diminished in size.

The following is a list of the tests in use in the United States, Great Britain and upon the Continent.

(1) Holmgren worsted test.
(2) Holmgren worsted test as simplified by Thomson.
(3) Oliver's worsted test.
(4) Raleigh's matching test.
(5) Edridge Green classification test.
(6) Edridge Green pocket test.
(7) Edridge Green lantern test.
(8) Edridge Green color perception spectrometer—New test for color blindness.
(9) William's lantern test.
(10) Thomson's lantern test.
(11) Nagel's card test.
(12) Nagel's anomaloscope test.
(13) Stilling's card test.
(14) Mayer's contrast paper test.
(15) Cohen's card test.
(16) Abney's pellet test.
(17) Field test.
(18) Buxton's marine telichrome.
(19) English Board of Trade modification of Holmgren's test.
(20) English Board of Trade new lantern test.

Space will not allow a description of these tests nor is it essential to this contribution, although a few words as to their adequacy may not be amiss.

ADEQUACY OF VARIOUS TESTS.

It is generally conceded among ophthalmologists and physicists that the Holmgren and other wool tests carried out as directed by their authors are not reliable tests and will exclude individuals who have normal color perception, at least a large number of candidates have been rejected because of faulty selection of the wools who have upon appeal been subsequently passed after a careful examination by an expert. It has also been shown conclusively that the Holmgren test misses about one half (or according to German authorities more than one half) of those who are dangerously color blind and are at once detected by use of one of the various forms of lanterns for detecting color blindness. The Holmgren wool test is criticized as being unfair in that it is too arbitrary and involves processes with which a candidate is absolutely unfamiliar and the verdict depends largely upon the tact, patience or ill will of the examiner. This test when carried out according to directions is lacking in one of the first essentials

of a test for color blindness, *i. e.,* that color names should be used and that a person to be examined should employ and understand the use of the color names red, yellow, green, blue and white. Edridge Green says:

The method of matching colors should, in order to be efficient, be one of mentally naming them. For instance, if a man say to himself, "This test color is green; therefore I must pick out all the colors having this hue of green in them," he will go through the test as it should be gone through; but if on looking at the wools he be more influenced by shade, he will put light blues, yellows, greys, and browns with the green. This will be especially liable to happen in cases of the lesser degrees of color blindness, in which the green is simply enlarged and encroaches on the yellow and blue. It is not necessary he goes on to say "that the color names used be those used by me; any name will do." *The essential point is that color blindness is shown by a person including two colors of the normal sighted under one name.*

The pseudo-isochromatic tests such as Stilling's and Nagel's plates have occupied a first place in tests for color blindness and as Edridge Green states:

If cases of color blindness were identical these methods would be more reliable than they are. Cases of color blindness, however, differ; in fact it is difficult to find two cases exactly alike. If a pseudo-isochromatic match be found for one dichromic and letters of the one color be printed on a background of the confusing color he will not be able to read them. Another dichromic, however, may be able to read these letters quite easily. For instance, he may have much greater shortening of the red end of the spectrum, and the subtraction of the red rays from one color will make that color much darker than the other color confusion. On account of the fact that simultaneous contrast is increased in the color blind, it is necessary that both colors of confusion should correspond to two points well within the monochromatic regions of the observer. These are the main objections to pseudo-isochromatic tables, if we exclude the extreme difficulty of accurately producing them. Quite apart from this the fact that the two colors are regarded as identical by the color blind can be utilized in a far easier and more satisfactory manner.

Marshall states:

The test with Nagel's anomaloscope is hopelessly inadequate because many normal-sighted people vary greatly in the proportions of red and green which they use in order to produce yellow, while many color blind people make the match with precisely the same proportions as the majority of normal-sighted people. Further, in a recent paper before the Royal Society, Edridge Green showed that color weakness and anomalous tri-

chromatism are not necessarily associated, and if this be so the test fails at once.

As regards lamp or lantern tests the consensus of opinion seems in their favor, inasmuch as the examination of a candidate by means of them shows conclusively whether he can name and distinguish colors of the lights which he will be required to recognize in pursuit of his duties in railway and marine service.

The use of any of the color matching tests is as a rule supplemented by other tests such as the anomalscope, Raleigh's matching lantern or the various lanterns in use.

The dangers in marine and railway service from defective color sense in the past have been great enough, but from all indications *the absolute elimination of all persons with subnormal color vision in railway service in the future is imperative,* inasmuch as the trend of railway signaling is toward light signals by day as well as by night.

The ordinary semaphore lantern used for night indication is, strictly speaking, a light signal; it projects a beam of approximately 60 candle-power which, while sufficient for a range of one to three miles at night, depending upon atmospheric conditions, is not designed for daylight indications.

Small light signals having a daylight range of 100 feet or more have been used for years on trolley roads, principally to hold cars on passing sidings; they have also been used in tunnels and at stations, locations where the subdued light is favorable for displaying a signal of low candle-power. The first extensive application of light signals to railroad service was the installation on the Pennsylvania Tunnel & Terminal Company in 1910, the indications being given by one 40-watt tungsten lamp behind each colored lens. In these signals it was not necessary to secure a range of more than 500 feet, consequently small lenses with large lamps behind them so arranged as to give considerable spread to the projected light were found satisfactory. The increasing need for longer ranges at low power consumption has determined a marked increase in the efficiency of light signals so that now the candle-power of a light signal has been made 15 or 20 times greater, at the same time that an actual reduction in power consumption has been secured, all this being accomplished

by employing lamps and lenses of the highest possible efficiency. The range of these light signals for day indications as worked out is about 3,000 feet for the standard red and green and 2,000 to 2,500 feet for yellow.

Many factors interferring with color vision are to be found such as: (a) conditions existing about an engine; (b) atmospheric conditions; (c) condition of the signals themselves; (d) neighboring lights; (e) dusk and dawn.

Conditions existing about the engine, such as the escape of steam when an injector is used, when the whistle is blown, from leaking valves or connections, from the poorly packed piston rod of air pumps, cylinders and steam chests, will often completely envelope the engine and cab. Steam and soot from the smoke stack is often blown back against the cab windows, covering them with moisture and dirt and making it next to impossible to see through them, to say nothing of obtaining a view of anything through the condensed steam and smoke. This is especially true in passing under viaducts or bridges and through tunnels entering the railroad yards of large cities, where there are many moving engines and trains, and signals must be closely watched. In freezing weather the escaping steam is especially bad, as the windows are coated with ice, and vision through them is out of the question. The dust raised by passing trains often coats the windows, especially if they are damp from escaping steam; the engineman's position, being on the right side, escapes most of this, however, on roads which run their trains right-handed on double tracks. The cloud raised from ploughing through snow drifts shuts off all vision for the time. Considerable complaint is made of the drive wheels of the engine throwing mud and dirt on the front windows in moist weather.

The glare from the furnace door when the engine is stoked makes the recognition of night signals very difficult. There is an iron shield above the furnace door on the engineman's side. which protects him somewhat. Many enginemen have their seats curtained off to relieve them from this glare. After looking into this glow from the position of a fireman during the time required to shovel in five to six shovels of coal, it is an

utter impossibility because of the scotoma or black spot before the eyes for a novice to read a signal. Firemen state that they can not even see their steam gauge for several seconds after stoking, and when one takes into consideration that from three to ten tons of coal are handled in a two to five hours run, there is not much let up from looking into the fire box, and when this is done daily for five or six years, or even longer, before a fireman can expect to become an engineman, it must be a good pair of eyes that can stand it, without some protection.

The constant jarring, with the swaying and rolling of an engine traveling at a high rate of speed, is another factor in making signal reading difficult.

The constant supervision of an engine takes no small part of an engineman's time and attention, and his duties are far more than sitting on a seat and watching for signals. This is especially true when there is any trouble with the various mechanisms under his care.

Certain atmospheric conditions are not only a source of great annoyance in reading signals, but often completely obscure them at a distance, sufficient within which to control a train. Fog, snow, mist and rain take precedence in the order given, and when it is necessary for better vision to have the head out of the cab window the impinging of fine particles of snow, mist or rain, against the eyes blinds one almost instantly. The force of the wind when running at a high rate of speed causes the tears to flow and blurs the vision after a very short exposure. Night (illuminated) signals are usually seen at a greater distance than the day (position) signals in these atmospheric conditions.

Atmosphere laden with water vapor such as fog is a great factor in absorbing light and while the greatest absorption is at the red end of the spectrum with a gradual decrease towards the violet end, light having a preponderance of blue rays such as an arc light has a much shorter range in fog than a light source having a greater intensity in the red end of the spectrum such as a kerosene flame. There are no recorded data as to range reduction caused by fog, but, observation has lead to the conclusion that the range of a signal is frequently cut down to

1/20 of the clear weather range, while in dense fog the reduction is probably much more.

Rain and hail do not interfere as much with the range of a signal as other atmospheric conditions; however, tests conducted by the German Light House Board showed 30 per cent. reduction on an average, in rainy weather.

Snow interferes greatly by accumulating upon the roundels and lenses and markedly reduces the range of a signal if the air is full of flakes.

Dust and smoke in the atmosphere tend to shift the hue of a light toward the red end of the spectrum as they interfere with the transmission of the shorter wave-lengths. Dense smoke has an effect upon the range of a light similar to fog.

As may naturally be expected dirty roundels, lenses or reflectors greatly reduce range as well as change the saturation of the color. Alinement of the semaphore lamp with reference to the track has much to do with the distance a signal may be seen. The lens is so constructed as to converge the rays of light falling upon it in a relatively parallel beam, a slight deviation in the adjustment of a lamp will throw the axis of the beam off the track as well as reduce the amount of light projected in the desired direction.

Neighboring lights which may be mistaken for signal lights are kerosene, gas, incandescent (carbon), arc and acetylene lamps. This is more liable to occur if there is smoke or dust in the air.

Dusk and early dawn are times of day when signals are most hard to recognize. There is not sufficient daylight to determine the position signals and what daylight there is seriously interferes with recognition of the night signals.

Thus it will be seen from the factors enumerated above, those requiring good vision and those tending to interfere with it, that the best known standard of binocular single vision and color perception is none too good, and not only must the man have this, but it must be "quick vision," for he may for an instant be able to see through some break in the interfering media, and must be able to read his signals in that instant.

DISCUSSION.

Mr. A. H. Rudd (Communicated): I must take issue with the author's statement that "the indication of a signal must be recognized at a distance not much less than a half mile in order to control the movements of many of the limited trains." With signals properly arranged and proper approach indications given, it is unnecessary to see signals at any such distance; in fact, it is safe to operate at high speeds in a fog where signals cannot be seen more than five hundred or six hundred feet. On many crooked roads, it is impossible, in many cases, to get a longer sight than this, even under the most favorable weather conditions.

This paper is a very interesting one and certainly well worth reading. It is a pity that the author did not give us some definite conclusions as to the arrangement and selection of colors which would give the very best results.

On the fifteenth page he gives the conditions existing about the engine which make the reading of signals difficult and I feel he exaggerates a little in this regard. I do not think that generally the "drive wheels of the engine throw mud and dirt on the front windows in moist weather" as they are pretty well covered on top, and the amount of mud on the tracks over which very fast trains are run is not a perceptible factor.

It occurs to me that colored glasses for the use of firemen and enginemen will minimize the bad results due to stoking and to fine particles of snow, and wind, which would cause the eyes to water and blur the vision. In fact, in addition to the wind shields, etc., on the locomotives, it is a general practise on the Pennsylvania Railroad for the drivers of fast trains to wear such glasses.

Dr. Daniel Witwer Weaver (Communicated): First considering only the function of the normal eye. The "visual-purple" or pigment of the retina is decomposed or destroyed by the action of light upon it, somewhat similarly to the chemical decomposition of the nitrate of silver of the photographic plate, but with this difference, the latter one is a purely chemical process, while the former is a bio-chemical process. The normal eye will reproduce the pigment of the eye if protected from the light as by closing the eyes in winking and in sleep. When the

eyes are open, and the retina is exposed to light, no matter what color the rays may be, the consumption of the visual-purple proceeds. When light is shut out (even for a moment as in winking, and during sleep) the reproduction proceeds.

The law of production and consumption is the same here as elsewhere. I believe in numerous cases when the railway employees fail to distinguish signals, it is because the eyes were in use for too many hours successively; the consumption has exceeded the production. This is equally true when the eyes are subjected to intense light.

The engineer facing the sun near to the horizon, especially when the ground is covered with snow, is consuming the visual purple faster than the production, hence his visual acuity is very much lowered for the time being. Alcohol, nicotine, and syphilitic poisoning reduce the pigment production process. These three elements combined with long hours of overuse of the eyes are causes of diminished visual acuity.

Climatic conditions, such as fog, rain, steam, wind, etc., will reduce one's perception of signal lights very much and yet I know of nothing that will remedy this condition except more candle-power.

Another consideration of the color light signals that must not be overlooked that is the fuel used. The green glass in the semaphore is not equally green to the eye when illuminated by kerosene and incandescent electric lamps, even if the candle-power is the same; and the same is true with regards to the yellow, red and purple lights, because of the varied composition of the light itself. Of course the more thorough the color saturation the less the variation.

THE DESIGN OF ILLUMINATED SIGNS.*

BY ARTHUR H. FORD.

Synopsis.—This paper describes and gives the results of some tests of visual acuity in which the test object consisted of two bright lines on a dark field. The facts determined are made the basis for the formulation of certain rules for the design of illuminated signs which are required to be legible at a certain distance. The rules are checked by application to individual letters and a small group.

No one can take an evening stroll on the streets of even our smaller cities, in this age of universal advertising, without being confronted with all sorts of illuminated signs, some of which make a lasting impression on the stroller, though more do not. The making of a lasting impression is the reason for the existence of the sign; therefore it should receive careful consideration at the hands of the manufacturer. A sign can easily be made to attract attention by making it the brightest object in the field of view or by making the design, or a part of it, flash; but, no matter what is done to attract attention, it is necessary to have the sign carry an easily read legend if the impression made is to advertise a certain object. Mere brightness often defeats the purpose in view by making the lettering on the sign illegible.

The object of this paper is to set forth the laws governing the legibility of illuminated signs and a method of design which will procure legibility at any pre-determined distance.

The legibility of a sign consisting of one or more letters is dependent on the acuity of vision of the observer, that is his ability to distinguish detail. Take, for example, a white block letter B on a black background. When the observer is far away he will see only a white spot; but, as he approaches the letter, he will finally reach a place at which he will be able to distinguish the letter, as such. The explanation of this phenomenon requires a knowledge of the anatomy and physiology of the eye; so a brief discussion of these subjects will be interpolated at this place.

The retina of the eye, when viewed through a high power mi-

* A paper to be presented at a meeting of the Illuminating Engineering Society Chicago, Ill., June 10, 1914.

croscope, is seen to contain a layer of enlarged nerve cells called the rods and cones, which perform the function of transforming the light energy which they receive into nervous energy, which makes an impression on the brain. The retina being a cellular structure, it is easily perceived that there is a limit to the fineness of detail, in the image cast thereon by the light passing through the lens, which can be transmitted to the brain. Two points can be distinguished as separate entities only when their images are formed on separate rods or cones. Fineness of detail can be perceived only by coming closer to the object, so as to have a larger image of it formed on the retina.

When one wishes to see the detail of a certain object within the field of vision he unconsciously turns so that the image of that object falls on the fovea of the retina, at which point the greatest detail can be perceived. The acuity of vision will therefore be determined by the spacing of the cones in this part of the retina, for the rods are absent here. Careful measurements show that the distance between the centers of the cones is approximately 0.007 millimeters at this point and that the distance of the center of the lens from this point is approximately 15 millimeters. This makes the maximum possible acuity about 2,000, as measured by the ratio of the greatest distance away from two parallel lines, at which they appear as separate lines, to the distance between them. The published data on this subject give the same value to this constant, derived experimentally, as that derived above from the dimensions of the eye; but when an attempt is made to apply this value, in the design of an illuminated sign, it is found that the sign cannot be read at as great a distance as was calculated.

An investigation of the literature of the subject shows that the experimental data from which the acuity constant of 2,000 is derived were determined by the use of two black lines on a white field, which is exactly the reverse of the conditions encountered in illuminated signs. The writer therefore found it necessary to check the results for the conditions under which an illuminated sign must be read.

A determination of the visual acuity of six subjects was made under the following conditions. A miniature incandescent lamp

having a single loop carbon filament with parallel sides was mounted on a rotating standard and so screened that an observer 1 meter distant from the lamp could see two parallel parts of the filament, each 5 millimeters long, 0.05 millimeters in diameter and 3 millimeters apart when the plane of the filament was at right angles to the line of sight (Fig. 1). The lamp was then rotated so that the two parts of the filament came closer together, as viewed by the subject, until they apparently coalesced. The lamp was then turned from a position in which the line of

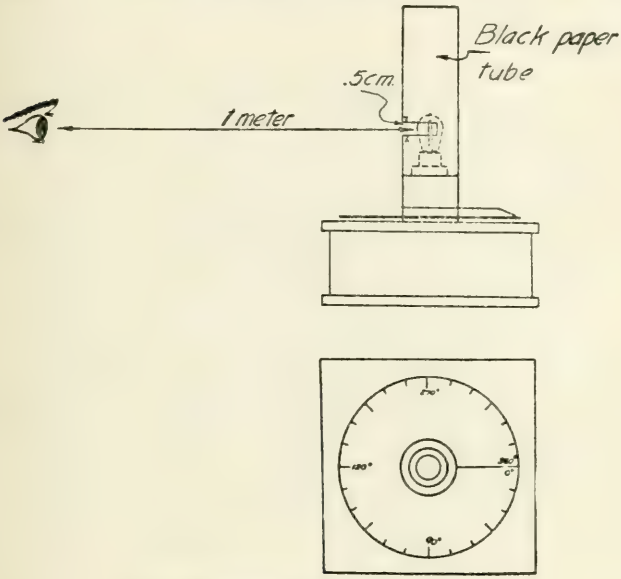


Fig. 1.—Apparatus for testing visual acuity.

sight was in the plane of the filament until they again appeared as two. The lamp was then operated at a different voltage and the experiment repeated. The average results are plotted in Fig. 2 and the indivdual readings given in the appendix, Table I. The lowest voltage at which tests were made was that which lighted the filament so that it could just be seen against the black background. When the lamp was operated at normal voltage the effect of eye fatigue was so great that no satisfactory results could be obtained.[1]

[1] The effect of eye fatigue was the production of black lines which were confused with the dark space between the two portions of the filament.

The curve shows that there is a marked diminution of the visual acuity as the intrinsic brilliancy of the filament increases. The following explanation of this phenomenon is offered. Whenever the images of two parallel lines are formed on the retina, the lines appear as one unless the images are far enough apart to leave a row of cones between them which are stimulated weakly or not at all, in the case of two lines lighter than the background, or a row of highly stimulated cones, when the lines are darker than the background. When the stimulus is intense the effect is not confined, apparently, to the cones upon which the

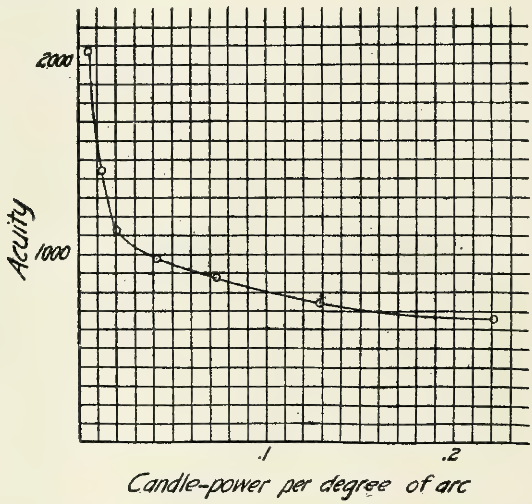


Fig. 2.—Effect of luminosity upon visual acuity.

image falls, but spreads to the adjacent cones; so that two bright images must be further apart in order that there may be an unstimulated row of cones between them than is required of two dark lines in order to have a row of stimulated cones between them.

The relation commonly given, that visual acuity increases with the illumination intensity, is not disproved by the experiments described above; for the acuity is commonly determined for black lines on a white background and for illumination intensities much lower than those used in this case.

SOLID LETTER SIGNS.[2]

The most important rule to follow, in the design of solid letter signs with a dark background is that the distance between the letters and the elements of the individual letters must be greater than the maximum distance at which the sign is to be read divided by the visual acuity for the letter luminosity used.

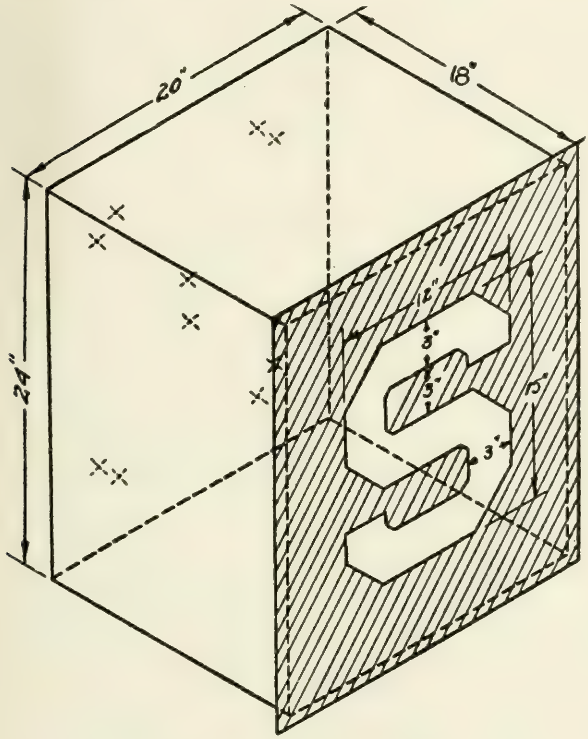


Fig. 3.—Test letter for solid sign.

When the sign has dark letters on a light background the width of each element of a letter must be greater than the maximum distance at which the sign is to be read divided by the visual acuity for the luminosity of the background. The letters of a dark letter sign will have to be of greater size than those of a light letter sign in order to have them of equal legibility.

[2] A solid letter sign, in this discussion, is a sign in which the letters have their elements of a solid color, as distinguished from one in which the letters are made up of points, as dark or light dots.

The rest of the design consists in the determination of the proper luminosity which the letters or the background shall have. This does not allow of exact determination on account of its dependence on the brightness of the surroundings, which affects the pupilary opening of the eye. However, a luminosity of 3 lumens per square foot (32. lux) will be found satisfactory under most conditions.

This method of design was tested for a single letter as follows: A letter S was cut from pasteboard and the opening covered with white tissue paper. This was made the front of a box having a white lining, and containing incandescent lamps, as shown in Fig. 3.

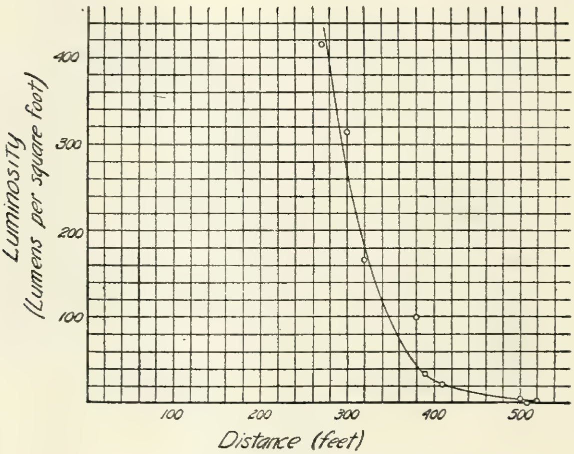


Fig. 4.—Legibility test of solid letter sign.

An observer would go to such a distance that he could not distinguish the letter and then walk toward it, noting the point at which it became easily legible. The number of lighted lamps in the box was then changed and another observation made. The results, Table II of appendix, plotted in Fig. 4, were obtained when there were several incandescent lamps within the field of vision, though the immediate surroundings of the letter were dark. The luminosity of the translucent letter was obtained by direct measurement with a photometer. A curious effect noted is that as the luminosity is increased the distance of

legibility first increases and then decreases to a fairly definite minimum. The best luminosity is seen to be low, as compared with current practise for signs of this type.

POINT LETTER SIGNS.

The designer of point letter signs is between *Scylla* and *Charybdis;* for he must keep the distance between the separate letters and parts of the same letter, greater than the distance of the observer divided by the visual acuity for two bright lines, when the observer is at the maximum distance at which the sign is to be read; and at the same time have the distance between the lamps on each element of each lettcr, less than the distance of the observer divided by the visual acuity for two bright points, when the observer is at the minimum distance at which the sign is to be read. These requirements put severe limitations on the range within which point letter signs are legible without the use of an excessive number of lamps for each letter. The minimum number of lamps which can be used in a letter of this kind is determined by the fact that it requires two points to indicate a line; therefore the lamps must be so closely spaced that there will be two in the shortest element of the letter. This requires a sign, with the width of the letter four-fifths the height and made up of equally spaced lamps, to be at least five lamps high.

Signs made with a large number of lamps per letter stand out very prominently as regards legibility, even though others in close proximity may have much larger lamps and a greater total light flux.

When one approaches a point letter sign from a distance he first sees a blur of light, then the letters and a little later the individual lamps; at which time the forms of the letters almost disappear. This is especially noticeable when approaching the sign at an angle. These defects can be overcome, to a considerable extent, by using frosted lamps, which increases the apparent size of the light sources and therefore decreases the distance at which the images of the separate lamps appear as a continuous line.

Point letter signs made up of illuminated "bull's eyes" are or-

dinarily more legible than those made up of lamps, because. owing to the facility of their construction, it is customary to make them with more luminous points than would be the case if separate lamps were used for the luminous points. They have the further advantage that they are almost as legible in the daytime as at night.

COMBINATION SIGNS.

The defects of the point letter sign are overcome, to a considerable extent, while retaining the drawing power of its brilliancy, by mounting the lamps on a solid letter sign with light colored letters. This is because the reflection of light from the letter serves to fill up the otherwise dark gaps which are seen when one views a point letter sign from near at hand. Most makers use too few lamps per letter, in signs of this kind, as is shown by the following experiments.

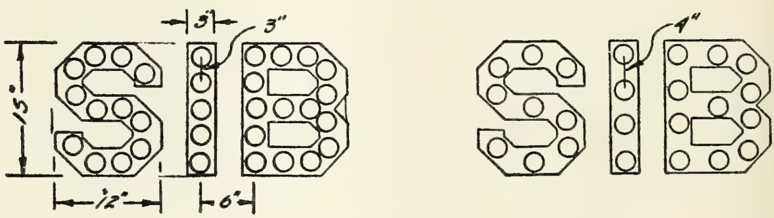


Fig. 5.—Test Letters for point letter and combination signs.

The letters S I B were cut from wood and had lamps mounted on them as shown in Fig. 5.

These were tested for the maximum distance at which they were legible, with the lamps operated at various voltages, both in the case of a black letter on a black background and a white letter on a black background. Tests were first made on the four lamp high letter with the letters spaced 3 inches (7.6 cm.) apart; then with the distance between the letters increased to 5 inches (12.7 cm.); and later on the five lamp high letter with the distance between letters 3 inches (7.6 cm.).

The results, table III of appendix, which are plotted in Fig. 6, clearly show the superiority of the combination letter sign and the five-lamp-high letter. These experiments show that it is futile to use high power lamps for the letters of illuminated

signs unless they are of such size that a large number of lamps can be used for each letter and are to be viewed from such a distance that the brilliancy of the image formed on the retina is comparatively low.

The writer suggests as the most desirable sign, for ordinary use, one with solid letters for the legend, with a border of lamps, where it is desired to attract the attention of the passerby by

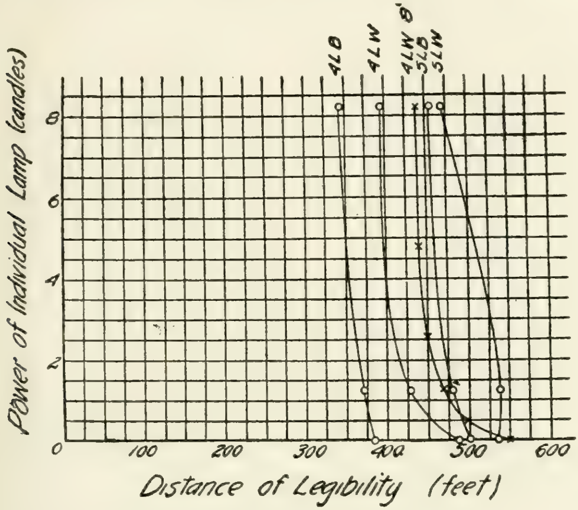


Fig. 6.—Legibility test of various letters.

4 L B = 4 lamp high latter with black background.
4 L W = 4 lamp high latter with white background.
4 L W = 4 lamp high latter with white background; 5" letter spacing.
5 L B = 5 lamp high latter with black background.
5 L W = 5 lamp high latter with white background.

means of the brilliancy of the sign. The spaces between the letters, or parts of the same letter, should be greater than the distance of the observer divided by 1,000, when the observer is at the maximum distance at which the sign is to be read.

The next best sign, from the standpoint of legibility, is one with trough-shaped letters, supplied with bowl-frosted lamps having filaments shaped like a V, with the top toward the trough (Fig. 7). The lamp recommended will serve to illuminate the letter fairly uniformly and, if the frosting is thick enough, will reduce the light received directly from the lamp to the same in-

tensity as the reflected light received from the trough. The shape of the trough is such as to equalize the light given off in different directions so as to make the legibility fairly independent of the angle at which the sign is observed.

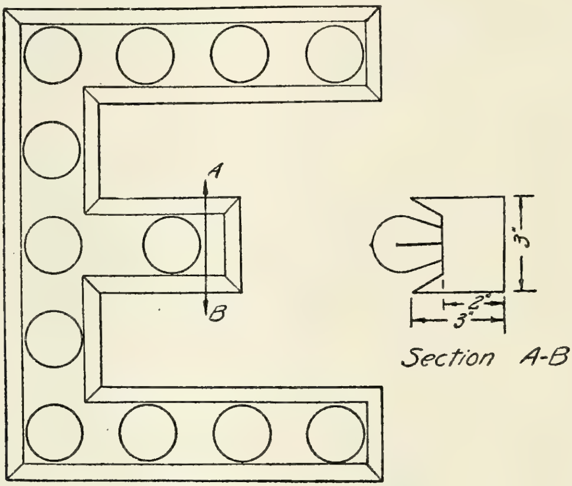


Fig. 7.—Trough shaped letter.

The following of the simple rules given above will place the designing of illuminated signs on a strictly scientific basis, as regards the obtaining of legibility and therefore reduce much of the waste in advertising by their use.

The writer hereby expresses his appreciation of the services of Mr. J. H. Edwards in carrying out the legibility tests.

APPENDIX.

TABLE I.

Power of Lamp (Candles)		Subject						
		Visual Acuity.—Observer distance ÷ Filament separation						
Per cm. of filament	Per degree of arc*	M.	St.	Y.	V.	Si.	F.	Average
0.003	0.005	1490	3220	1670	1610	2040	3340	2080
0.007	0.012	1150	2040	1430	1110	1350	2320	1450
0.012	0.021	920	1300	1090	960	1270	1410	1130
0.024	0.042	980	980	960	710	1070	1370	980
0.042	0.074	760	1070	860	730	890	1140	890
0.075	0.128			740	680	710	840	740
0.125	0.221	610	870	570	550	580	570	660

* The arc referred to is that subtended at the eye of the observer by the lamp filament.

TABLE II.

LEGIBILITY TEST OF A 15-INCH* TRANSLUCENT LETTER SIGN.

Maximum distance of legibility (Feet)	Luminosity of letter (Lumens per sq. ft.)
270	415
300	295
320	167
380	100
390	34
410	10.6
480	2.4
500	1.6
490	0.2

TABLE III.

LEGIBILITY TESTS OF POINT LETTER AND COMBINATION SIGNS.

Power of individual lamps (Candles)	Maximum distance of legibility (Feet)	Kind of letter
8.24	395	4 lamp high. White.
1.24	430	
.05	488	
Legibility limited by letter spacing and likeness of S and B.		
8.24	344	4 lamp high. Black.
1.24	370	
.05	380	
Legibility limited by lack of outline of letter; too few lamps.		
8.24	440	4 lamp high. White.
4.79	440	5 in. (12.7 cm.) between letters.
2.55	450	
1.24	470	
.52	500	
.18	500	
.05	440	
Legibility limited by indistinctness of individual letters; showing that wider spacing does not increase legibility. Surface of letter only slightly illuminated at lowest power of lamps.		
8.24	520	5 lamp high. White
1.24	540	
.05	535	
Legibility limited by indistinctness of individual letters.		
8.24	460	5 lamp high. Black.
1.24	480	
.05	500	
Legibility limited by indistinctness of individual letters		

* 38.1 cm.

DISCUSSION.

Mr. Oscar P. Anderson (Communicated): The problem of designing the electric sign so that it will operate at its maximum efficiency, from an advertising standpoint, is of considerable concern to sign manufacturers. It is obvious that the advertiser is also anxious to get the maximum results from the expenditure which he makes. Sign manufacturers have recognized this and have been constantly striving to improve the legibility as well as the attractiveness of their signs. There is no question in my mind but that the quality of electric signs from every standpoint has improved materially during the past few years.

This paper takes up the design of signs only as affected by the legibility. Data of this nature is valuable since it can be put to practical use. However, in a design of a sign there are a number of things which must be considered apart from legibility. A sign must not only be legible; it must also be attractive and attention compelling. There are a number of signs which can be considered models from the standpoint of legibility but from an advertising standpoint they are not a success since there is nothing about them that will attract the attention of a passerby. The curves in Fig. 6 show that with the same spacing lamps of a low candle-power are more desirable than lamps of high candle-power, since the sign can be read at a greater distance. Although this is undoubtedly true of smaller signs, I do not believe it holds true with large roof signs. I know of one large sign which is illuminated by 25-watt lamps and to me it appears as a good example of legibility. I believe it would be interesting if Mr. Ford could extend his investigations so as to include larger signs.

The tendency during the last couple of years has been to replace the 2 and 4 candle-power carbon sign lamps with the 10-watt tungsten lamps giving approximately 8 candle-power. With the exception of very small block or flush signs, I believe the change has resulted in a marked improvement in the appearance of the signs and the merchants have undoubtedly thought the same or otherwise they would not have made the change.

The curve in Fig. 4 tends to show that as luminosity decreases, the legibility increases. This is undoubtedly true within certain limits but I do not believe that the legibility will continue to increase until the luminosity reaches zero as is shown in the figure, although I have no data with which to support my contention. It seems reasonable to assume, however, that there is a definite intensity at which the maximum results will be obtained and that to go either below or above this intensity will cause a decrease in legibility.

The frosting of incandescent lamps will undoubtedly increase the legibility of a sign but in spite of this fact I do not believe it desirable to recommend the general use of frosted lamps in signs. The frosting on a lamp will cause it to collect dirt and grease which will greatly impair its efficiency under service conditions. If the sign were cleaned at regular intervals, this would not be true, but unfortunately there are very few signs which are systematically inspected.

DISCUSSION.

Mr. Evan J. Edwards (Communicated): A reading of this paper by Prof. Ford causes one to wonder why the sign design problems have never been attacked in a scientific manner the same as other lighting problems. That they have not been the subject of scientific investigation by the designers is evident to the most casual observer. More than half of the present-day electric signs are absolutely illegible from points included in a large proportion of the area from which they are visible. A sign which is not readable from a large portion of the area over which it is visible is, of course, inefficient and represents a certain waste of money. A little consideration given to the simple laws governing the legibility of illuminated signs would prevent much of this waste which is going on at present.

Some tests similar to those reported by Prof. Ford were recently made in the laboratory of the National Electric Lamp Association, and a number of people seemed to be considerably surprised to find that the readability distance increased as the brilliancy of the sign was lowered below the usual values. Our results in this respect agree very well with those given by Prof.

Ford, and in our experiments the change of brilliancy was accomplished by changing lamps rather than by varying the voltage, which would indicate that the relation of readability distance to brilliancy is a fundamental one which does not involve the color question to any considerable degree. It would be very interesting to carry the experiments to extremes of color, far beyond that which comes incidently with the change of voltage on the lamps.

It seems evident from the results shown by Prof. Ford and from the aforementioned work that signs cannot be operated at the brilliancy which would give the maximum readability distance, for such a value of brilliancy would be so low that the sign would no longer be striking in appearance; it would become insignificant as compared with its more brilliant neighbor. The best combination as regards brilliancy and readability can no doubt be obtained with a uniformly bright letter and in this respect the trough letter would seem to have considerable advantage.

Another point which I would mention is in relation to signs to be viewed at considerable distance. We have attempted to determine experimentally the relation of letter dimensions, width of scroll, and spacing to distance of observation. This point is important only in connection with signs viewed at considerable distances, say a quarter of a mile or more. Our observations indicate that the proportions of the letter should be increased more than in proportion to the distance of observation. This is probably due to poorer definition brought about by the diffusion of light by the vapor and dust particles in the intervening air.

Prof. Ford's very valuable paper should stimulate a new interest in the questions concerned in the proper design of electric signs.

NOTE: Additional discussion on this paper will appear in the next issue of the TRANSACTIONS, No. 6, vol. IX.

ILLUMINATION AS A SAFETY FACTOR IN INDUSTRIAL PLANTS.*

BY R. E. SIMPSON.

Synopsis: At the present time not enough emphasis is given by various labor bureaus to the importance of good lighting and its relation to accident prevention. Factory owners are furnished with all manner of statistics on accident prevention, but little is said regarding illumination. The close relation of the accident rate during the working hours under artificial light and daylight is illustrated in Figs. 1 and 2. Spotted illumination, because of its demands on the eyes, tends to increase the opportunities for accidents. Stairways and passageways are generally inadequately lighted, and falls, causing serious accidents, are frequent in these places. Unshaded lamps, especially those of high intrinsic brilliancy, greatly increase the hazards to workmen. The industries in which poor lighting conditions greatly increase the opportunities for accidents are construction work, ship building, foundries and iron and steel mills.

From time to time we read in the technical press that 500,000 avoidable accidents occur in the United States every year, and that of this number approximately 25 per cent. are due, directly or indirectly, to inadequate illumination or improperly placed lighting units. To get proof of this statement in the form of statistics is almost impossible. Reports are issued annually by the labor bureaus of various states, and by the Federal government, containing tables giving the number and causes of various classes of accidents. The causes that are listed include the breaking of hoists, cranes, winches, and other machines, the bursting of grindstones and emery wheels, the improper use of circular saws, lathes, and presses, contact with mill gearing (shafts, pulleys, and belts), and persons falling or being struck by falling tools or other objects. Rarely, if ever, is poor illumination among the list of causes, although many of the reports mention poor illumination as an indirect or contributory cause. The paucity of statistics on the relation of illumination to accidents is responsible, in a measure, for the apathy of factory owners and managers toward their lighting conditions. A manager, upon noting that such and such a number of workmen were injured by

* A paper read at a meeting of the New York Section of the Illuminating Engineering Society, April 9, 1914.

unguarded gears, at a cost to the employer of so many dollars paid to the injured employee in the way of compensation or in the settlement of damage claims, is often led to see that his mill has adequate protective devices; but there is very little chance of his attention being directed to his lighting conditions by the statistics, and if it is true that 25 per cent. of the avoidable accidents

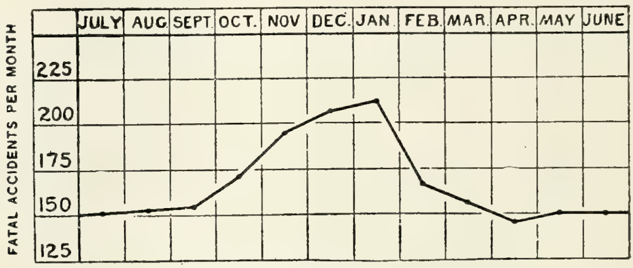


Fig. 1.—Showing relation of daylight to accidents.

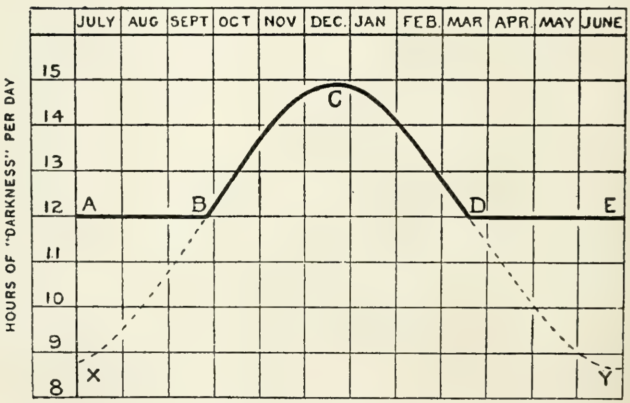


Fig. 2.—Distribution of darkness by months.

are due to inadequate illumination, he is overlooking an exceedingly important item.

For the purpose of showing the relation of illumination and accidents I have taken Figs. 1 and 2, and the text describing them, from the April, 1913, issue of the Travelers Insurance Company's monthly periodical known as *The Travelers' Standard.*

"The importance of good illumination, from the standpoint of safety to the workman, was well shown in a paper read by Mr. John Calder before the American Society of Mechanical Engineers, and printed in the *Journal* of the society for February, 1911. Mr. Calder shows the number of persons that were fatally injured in a large group of plants, during a period covering three consecutive years—grouping the data according to the months of the year.

"His general results are shown in Fig. 1, though we have modified the plan of presentation somewhat, believing that we have thereby made the influence of good light upon the death list even more evident. Mr. Calder gives a curve for each of the three years, separately; but we have combined the three curves into one, including under August (for example) all the accidents that have occurred during the month of August, without regard to the year—and so for each of the other months.

"Each of the dots at the angles or joints of the full line in Fig. 1 represents, by its height on the scale at the left, the number of accidents for the corresponding month.

"When all twelve of the dots had been located in this way, the irregular line that is shown was drawn between them, so as to show the general course of the accidents and to exhibit to the eye, as clearly as possible, the way in which they varied in number in the different months of the year. It will be seen that during July, August, September, March, April, May and June, the number of accidents per month (for the entire three-year period) remained practically constant, and equal to about 150. In other words, the diagram shows that when the day was long enough to give good illumination throughout the working hours, the number of fatal accidents was fairly uniform, and about 150 per month; but that when the hours of darkness increased, the number of accidents increased at the same time, so that in December and January it was no less than 40 per cent. greater than the normal number of 150 that might reasonably have been expected, if the daylight were as good in the winter as in the summer.

"Fig. 2 shows, in a similar diagrammatic way, the number of hours of darkness that there are, in the latitude of Hartford, in each calendar day of 24 hours, throughout the year—the word 'darkness' being here used, for the sake of brevity, to signify the period between sunset of one day and sunrise of the next day following.

"The diagram was drawn similarly to the one showing the number of accidents. Numerous points were laid off to represent, according to the scale shown at the left, the number of hours of darkness at the corresponding times of year. A smooth and continuous curve, X B C D Y, was then drawn through the points so located.

"The similarity in shape between the curves of the two diagrams, which is very marked, shows that there is a correspondingly close relation between the hours of darkness and the number of accidents. It could not be expected that the agreement would be good for the entire year,

because when the nights are short enough to ensure a good light throughout the working day, a further shortening of the period of darkness would not diminish the number of day accidents, but would affect night labor only.

"Assuming that the length of the night would have no influence so long as the period from sunrise to sunset exceeded 12 hours, we have drawn the straight horizontal lines AB and DE at the height corresponding to a 12-hour night; and to understand the real significance of the diagrams, the shape of the irregular line in Fig. 1 should be compared with the heavy line A B C D E in Fig. 2. When they are compared in this way, the influence of proper lighting upon accident prevention comes out very plainly indeed."

The following incident which recently came to the writer's attention illustrates the evils of "spotted illumination" and the danger to workmen if one of their number is afflicted with retinal asthenopia or temporary blindness, and shows how easy it is to overlook the real cause of an accident. Two men were at work in a shop lighted by electric incandescent lamps, equipped with obsolete tin reflectors suspended close to the work. The upper zone of the shop was in semi-darkness—a condition which became more pronounced to the workmen as they looked up from their work. Some sections of the machinery and floor were brightly lighted, while others were dim. In going to another part of the shop one of the men stumbled over a casting that was lying on the floor, and in an effort to save himself from falling he blindly put his hand on a belt-shifting rod which controlled the machine of another workman in the next row. This action threw over the belt and started the other machine. Fortunately no injury resulted, as the second workman had just finished a piece of work, and was engaged at the time in selecting another piece to put in his machine. It can readily be seen that a serious accident might have happened if the second workman had been engaged in adjusting the work in his machine, as he would have been totally unprepared for the starting of the machine.

The two men had a wordy war, the first workman blaming the man who had left the casting on the floor, while the second workman accused the first one of stupidity. Neither of them, apparently, considered the fact that the first workman was demanding an extraordinary performance from his eyes. There was marked difference in the reflecting values of the two parts of the castings

on which he had been working. One part was highly polished and had a high coefficient of reflection, while the other part was a dull iron-grey having a low reflecting value. The man's eye muscles had been under constant strain in an effort to adjust the pupillary opening to the light-reflecting conditions—the opening remaining relatively small, however, so long as the eyes were focused on the work. When he turned from his machine his eyes were compelled to adjust themselves to the change from a brightly lighted field of view to a dimly lighted one; and inasmuch as the eye muscles do not enlarge the pupillary opening as quickly as they contract it, he was laboring, for a time, under a serious handicap.

If the incident had had a serious ending, the newspapers would have reported the accident as due to a fellow workman accidentally moving a belt shifter and thus starting up his comrade's machine; but an impartial and well-informed jury would have given improper illumination as the cause.

To many persons this incident may seem trivial, and it would be so if it were an isolated case. There are hundreds of factories in this country where the lighting conditions are similar to those that prevailed in the case just cited, and these conditions are responsible, in the aggregate, for thousands of what might be termed potential accidents. The stage is all set and ready, and the frequency of accidents, or freedom from them, is largely a matter of chance, with the odds greatly in favor of the accidents. A little attention to the lighting details in these factories would materially reduce the chance of accidents, and would therefore reduce the number of them.

From a safety standpoint, as well as from a general illuminating engineering standpoint, intense local lighting, as the sole means of providing artificial illumination in a factory, is undesirable. A minimum of two-tenths of a foot-candle should be provided in *all* parts of a factory where a moderate degree of local illumination is required. In plants where fine tool-work is done, and fine bench operations are carried on, so that intense local lighting is required, the minimum for general lighting should be one-half a foot-candle. This minimum is also essential in a shop filled with moving machinery, especially if the men are

required to go from one part of the shop to another in the performance of their duties. Sharp contrasts between the intense local illumination and the low general illumination increase the hazards, because the employees, on account of their inability to see clearly, are apt to trip over obstructions in their path, or become caught in the machines or belts.

It may seem to some that I am giving too much emphasis to the subject of falls as a cause of accidents, but statistics show that this is not the case. The annual reports of the British factory inspectors show that for the year 1911 there were 379 fatal accidents caused by machinery moved by mechanical power, against 377 due to persons falling. The figures for 1912 are 382 and 419, respectively. Very few industries are exempt from accidents due to falls. They are most frequent in construction work and in shipbuilding, and in foundries and iron and steel rolling mills—industries in which poor illumination is notorious. Poor lighting on stairways and in passageways and aisles in shops is responsible for quite a fraction of these accidents. In many cases the working area in a shop is well lighted, while no provision whatever is made for lighting the stairways and passageways. There is no work done in these places, and for that reason it does not occur to the owner that they should be lighted. The steps of the stairways are generally dark-colored and worn round at the edges—conditions which increase the hazard. Substantial rail guards and stair treads, and lighting units with proper reflectors, should be part of the equipment of every stairway.

During a recent inspection the following conditions were noted. A 12-step stairway at one end of a room led from the basement to the first floor. The nearest lighting unit in the basement (an unshaded carbon lamp) was 35 feet (10.66 m.) from the foot of the stairs, and the nearest unit at the top was 20 feet (6.09 m.) away, a shadow being cast at the top by a post between this unit and the top step. An unguarded driving belt, extending half-way over the stairs, ran parallel to the stairway at a height of 5 feet 7 inches (1.7 m.). The belt was operated so that the turn on the under side ran down with the stairs. A person coming in contact with the belt would receive an impetus sufficient to hurl

him to the bottom of the stairs, causing him serious or even fatal injury. The belt should have been equipped with a guard painted white, and adequate light should have been provided so that anyone could clearly see the guard and the steps. When this was pointed out to the manager he agreed that these precautions should be taken, confessing at the same time that the danger had not occurred to him.

This brings out the point that making the general working conditions safer is often a matter of looking into the details of the lighting situation. The shop engineer and manager will generally give heed to the cost of installing, the cost of operation and maintenance, and the location of the lighting units, in the shop where work is performed; but the stairways and passageways, if considered at all, are provided with a lamp here and a lamp there, without due regard to the demands of safety.

In the ship-building trade a large percentage of the accidents that occur are caused by falls, and of this percentage the lack of proper lighting facilities is the greatest single factor. When a ship is building or being repaired, artificial lighting must be depended on, all the time, in almost every part of the ship. Generally speaking, adequate light is provided at the points where work is performed, but the lighting facilities from the working point through the ship to the shore are sadly neglected. The opportunities for falls are numerous, especially when the ship is being fitted out after launching. Open hatches, uncompleted and unguarded stairways, and gangways seldom, if ever, sufficiently lighted, are directly responsible for many serious and fatal injuries. If ship owners or builders would go to the slight expense of providing guard rails about stairways, platforms, bunker hatches, and openings into the hold, and see that these points are well lighted, the accident rate would be materially reduced.

Few of our large buildings have been erected without a certain number of the workmen being more or less seriously injured. We are all familiar with the appearance of a building under construction—the street protection, the piles of building material, the single-plank walks over the beam layers and the uneven and unfinished floors, and the gloomy appearance of the first floor in particular. Building material such as bricks, sand, and cement,

must be taken by hand from the point of delivery into the building, and the foremen usually drive the men so that the delivery wagon and the materials brought by it will obstruct street traffic as little as possible. A very limited number of lighting units are installed, in a more or less haphazard way, and these are depended on to light the working space and its numerous danger points. When the building is finished and the dangerous places have been eliminated, the amount of illumination is increased many fold. This, of course, is not at all consistent. The lighting facilities should be just as good during construction as after. Workmen carrying building materials are continually going from the bright daylight into the poorly lighted building, where they are unable to see their way clearly because of the great contrast in the lighting conditions; and this, together with the uncertain footing, greatly increases the hazards of their work, and is directly responsible for many accidents.

A great deal has been written and said in recent years respecting the merits, especially in the way of efficiency, of various kinds of lighting units. Salesmen have besieged factory owners and managers, the daily press and technical journals have been flooded with advertising literature, and bulletins have been spread broadcast, all for the purpose of bringing about a substitution of the more efficient units for the old, inefficient ones. The success of these campaigns is attested by the remarkable increase in the sales of the tungsten filament lamps, at the expense of the carbon and gem filament lamps. It is true that the introduction of the tungsten filament lamp has increased the degree of illumination in our factories and is an important item in the conservation of our resources; but I am of the opinion that it is equally true that the introduction of the tungsten filament lamp is the largest single factor for the increase of accidents in our industries during the period of artificial lighting.

The factory managers have gradually recognized the saving effected by the use of tungsten filament lamps. They have purchased them in large quantities, and have fatuously believed that by simply unscrewing a carbon or gem lamp from the socket and replacing it with a tungsten filament lamp of higher candle-power, of greater brilliancy, but consuming less energy, they have bettered

the working conditions of their employees and made a certain saving in their lighting bill at the same time. If the old lamp had a shallow, obsolete reflector, this reflector was left in place—not even the dust and dirt on it being disturbed. If no reflectors were in use, new, up-to-date ones were seldom purchased at the time of the change in lamps. The manager noted the reduced lighting bill, and may or may not have noted the increase in the number of accidents. Assuming that he did consider this item, an admonitory notice recommending more care and vigilance may have been issued, and not much thought given as to the cause of the increase in accidents.

It is well known among engineers that the rays of light coming directly from a light-source into the eye reduces the efficiency of the eye as a piece of visual apparatus. It is axiomatic that if a man cannot see his danger he is more apt to be injured than he would be if the danger were evident. An unshaded carbon filament lamp, directly in the line of vision, has a certain deleterious effect on the workman's rate of production and on his safety; and if for this carbon filament lamp a tungsten filament lamp with an intrinsic brilliancy two or three times as great be substituted, a slight increase in the quality and quantity of product may be evident, but this is gained at a considerable reduction in the factor of safety.

A 100-mile journey along a trunk line through a thickly settled territory would make a vivid impression on a person acquainted with the principles of illumination. The factories along the right of way give the impression of being well lighted—and so they are, if judged by the aggregate candle-power emitted by the light sources. A close observer would note, however, that many of the principles of good illumination are violated. There seems to be a decided lack of attention paid to the details of mounting-height, spacing, and reflector equipment, all of which have an important relation to the effective illumination. A good-sized reflector factory would have all the business it could handle for some time to come in equipping the factories between Hartford and New York with reflectors.

Just prior to an inspection the superintendent told the writer that his mill was well lighted, and several times during our walk

through the mill he complimented himself on the good illumination. There was one tungsten filament lamp, 150-watt size, suspended 7 feet 6 inches (2.28 m.) from the floor in one part of the room, just in front of a cutting machine. It was a clear lamp and the only one in the entire establishment with the dignity of a reflector, the reflector in this case consisting of a shallow piece of opal glass, 6 inches (1.52 cm.) in diameter. The rest of the lighting equipment consisted of 16 candle-power and 32 candle-power carbon lamps without reflectors, a few of them suspended 7 feet (2.13 m.) from the floor, but most of them from 5 to 6 feet (1.52 m. to 1.82 m.) It required less than five minutes conversation in the superintendent's office to show him the waste in using carbon lamps, and the greater safety and comfort of the employees and better lighted working space from the use of tungsten lamps equipped with modern reflectors and with the whole unit properly placed.

There is a crying need for a greater concentration of effort for the protection of the ultimate consumer of light, the eyes. Engineers and chemists have evolved lighting units, which if properly applied, will produce adequate illumination in our factories at a cost so slight that it is all out of proportion to its importance. The real problem seems to be the scarcity of men who are qualified to deal with the subject, and who can devote their time to it. There is a field for many times more men than are now available. The "Safety First" movement, and the recently enacted compensation laws, are creating a demand for expert advice on all matters pertaining to safety and sanitation, and the subject of proper lighting is bound to receive greater attention from factory owners than heretofore. It is here that the services of the illuminating engineer will be in demand, and in dealing with the problems he should bear in mind that one of the principal safeguards for any workman is unimpaired vision.

DISCUSSION.

Mr. G. H. Stickney (Communicated): Mr. Simpson has treated the subject principally from the standpoint of accident prevention. In its broadest interpretation, safety includes the preservation of health. Proper lighting is important in this connection for the conservation of eyesight. There are many proc-

esses of manufacture in which the eyes are required to give close attention to fine detail in order to insure good workmanship. This is true of lace making and various other processes in the working of textiles, as well as the finer working of nearly all materials. Office work also usually demands close application of the eyes.

Improper lighting induces eyestrain, which not only temporarily interferes with the efficiency of operators, but often results in permanent injury which may disqualify them for the work for which they are especially trained and may otherwise be particularly adapted.

From my own inspection of factory lighting, it has been evident that the fault has not always been lack of intensity; excessive glare, and improper direction of light are common defects. Nor are these defects limited to artificial light; they are common to daylight. Complaints are more common with artificial light because the possibility of correction is more obvious. Many times the correction takes the form of simply increasing the intensity, when better direction and diffusion are really more essential. On the other hand, artificial lighting intensities are much lower than those common in daylight. If the light is properly diffused, excessive intensity almost never occurs in artificial lighting, except from the standpoint of cost of illumination.

Mr. Simpson mentioned half a foot-candle as the minimum intensity allowable in a workroom. This seems to be a good average figure, although it is subject to considerable variation, depending upon whether surfaces are light or dark, as well as other conditions. In a large iron foundry where we made a study to determine the minimum intensity permissible for safety in moving around, we decided upon a value of one foot-candle. This higher value was due to the dark, non-reflecting surfaces and the presence of dangerous conditions.

As mentioned by Mr. Simpson, a few years ago the steel mills were especially dangerous on account of inadequate lighting. However, since the Association of Iron and Steel Electrical Engineers has been actively interested in illumination, these conditions have been greatly improved. A remarkable reduction in

the number of accidents is shown by actual figures taken over a period of years. I believe that no other industry has shown a greater improvement in this respect than the larger steel mills.

I am heartily in sympathy with Mr. Simpson's criticism of bad practise in using tungsten filament lamps and believe that all interested in the manufacture of incandescent lamps are anxious to see them used with proper reflectors. On the other hand, I do not believe that the substitution of higher power tungsten lamps for lower power carbon lamps usually makes poorer lighting conditions, although this is undoubtedly sometimes the case.

Mr. A. O. Dicker (Communicated): It is decidedly encouraging to see that increasing attention is being paid to lighting as a means of preventing accidents. However, many owners and managers realizing that their factory needs more light, unless coached in their lighting installation, are apt to go to the other extreme and use too much light, not realizing that they are incurring an equally dangerous condition. I have in mind a manufacturer that I have talked to a dozen times or more on the value of lighting who recently followed out, as he thought, the suggestions that I had made and installed a lighting system including reflectors which I really believe will blind the operators rather than furnish them the proper light.

The problem of placing guard rails around the danger points, encasing gears, etc., is undoubtedly necessary, but sufficient light so that the operator can see these points is still more necessary. A man will not put his hand or foot on a danger point if he can see it. A guard rail around a hole in the street is not considered sufficient. A light so that it can be seen at a distance must also be used.

One of the first opportunities of a "safety-first" crusade lies in an attack on the lighting conditions. The day will come when the eyes will be considered as important as the hands, legs or lungs.

Mr. Clarence E. Clewell (Communicated): Mr. Simpson has presented an interesting and important phase of factory lighting. The example of the workmen stumbling in the dark and by accident grasping the belt shifting rod of another man's

machine to prevent a fall is an excellent illustration of how shop accidents sometimes happen.

The author advances the value of two-tenths of a foot-candle as the minimum in all parts of a factory where a moderate degree of local illumination is required, and a minimum of one-half a foot-candle for general illumination in those cases where intense local illumination is required. He also condemns sharp contrasts between intense local and low general illumination as an effect calculated to increase accident hazard.

This would seem to emphasize adequate general illumination and the elimination of individual lamps as an advantage from the accident prevention standpoint, and the writer's experience seems to confirm this point.

The lighting of passageways and stairs is a matter apt to be overlooked and, as the author states, this condition is responsible for many accidents. The laws in Wisconsin and New York states require that such places be adequately illuminated and this feature of shop lighting may well be observed by all concerned.

The author makes an interesting statement to the effect that, in his opinion, the introduction of tungsten filament lamps is the largest single factor for the increase of accidents in our industries during the period of artificial lighting. A similar contention by others that eye trouble has been greatly increased since the introduction of tungsten lamps, makes it clear that the application of engineering methods to the use of electric lamps is important to-day as probably never before. Information should be spread broadcast among factory owners and managers calling attention to the fallacy of replacing old carbon filament lamps with tungsten units unless due care be given to the rearrangement of outlets and the use of suitable reflectors.

Taken as a whole, the paper is an excellent summary of the "safety-first" principles as regards one cause for accidents and should form valuable material in the nation wide campaign looking to greater safety and a reduction of accidents.

GLASSES FOR PROTECTING THE EYES IN INDUSTRIAL PROCESSES.*

BY M. LUCKIESH.

Synopsis: While it has been quite well established that there is little or no danger to eyesight from ultra-violet radiation when illuminants are properly used for ordinary purposes of illumination, occasions do arise in the industries where it is necessary to protect the eyes from ultra-violet rays and excessive amounts of radiant energy. This protection is accomplished by means of glasses which do not transmit the ultra-violet energy and which also reduce the retinal image to a safe brightness. Colorless or neutral glasses are to be preferred, but no glasses of this character have been found to be wholly satisfactory. As a general solution of the problem of eye protection it is proposed that a yellow-green glass totally absorbing ultra-violet be combined with a shade of smoke glass of such density as to reduce the brightness of the retinal image to a safe degree. Transmission curves of several characteristic glasses are shown. Spectrograms of the light from a quartz mercury arc and from an iron arc have been made through many samples of glass. For many cases the spectrograms provide sufficient data for analyzing the absorbing property of the glass. A brief account of experience with goggles and glasses in the industries is given. The paper is not intended as an exhaustive treatise on the subject, but data presented indicate the limitations and advantages of many common glasses and furnish information which has been collected for some time past.

INTRODUCTION.

The radiation from heated substances can be harmful to vision in several ways. The destructive effect of ultra-violet rays upon animal tissue has long been recognized. It is not definitely known which rays are the most destructive to animal tissue, although it is a fact that the rays of extremely short wave-lengths are very active in producing painful inflammation of the anterior surface of the eye. This fact has been demonstrated many times in working with light sources emitting large quantities of ultra-violet rays. Harmful effects arise sometimes when no glass intervenes between the eye and the source of these rays, while under the same conditions with the exception that a glass globe

*A paper presented at a meeting of the New York section of the Illuminating Engineering Society, April 9, 1914.

has enveloped the source no harmful effects have arisen. However it is quite likely that no harmful effects arise from the ultra-violet radiation from ordinary illuminants when the latter are used properly for illuminating purposes. There are however many special uses and industrial processes which require illuminants rich in ultra-violet radiation, all of which demand protection of the eyes by means of transparent glass media.

Another danger is met in these instances namely, excessively bright images upon the retina. There are on record many injuries of this character some of which are permanent. Again in the ordinary use of illuminants this danger is avoided by screening the light sources from the eye by means of shades or diffusing envelopes.

Another possible cause of impairment of vision might arise from the absorption of excessive energy by the eye media.[1] The thousands of cataracts encountered yearly in tropical climes suggests the possibility of the energy effect as the cause. Again it might be attributed to the ultra-violet rays. However, the well-known glass-blowers' cataract implies that the ultra-violet rays can hardly be the cause for molten glass emits an exceedingly small amount of these rays.[2]

The available data regarding the transmission of the eye media indicate that with the exception of the short-wave ultra-violet radiation the eye-media transmit radiant energy practically the same as water does. Pure water however is transparent to ultra-violet rays while the eye media are not. Scarcely any of the ultra-violet rays can reach the retina, for they are absorbed by the cornea and the lens. The various eye media vary in their absorptivity for ultra-violet rays. The cornea has about the same opacity for ultra-violet radiation as ordinary spectacle glass, transmitting no rays of shorter wave-length than about $0.295\,\mu$. The lens however absorbs a large fraction of the energy from $0.295\,\mu$ to the visible. Rays of wave-length in the neighborhood of $0.385\,\mu$ are strongly absorbed as is indicated by the fluor-

[1] "Radiant Energy and the Eye," *Electrical World*, October 25, 1913.

[2] Since preparing this paper Sir William Crookes has presented before the Royal Society an account of experiments in making glass for absorbing both the ultra-violet and infra-red rays. The work was done in connection with the Glass Blowers' Cataract Committee of the Royal Society. It appears that the committee has decided that the cataract is due to infra-red rays.

escence of the lens under radiation of this wave-length. In general ultra-violet rays of shorter wave-length than 0.350 μ can not reach the retina in great amounts, although there seems to be a region at about 0.325 μ which does not suffer as great absorption in the eye media as the radiation of adjacent wave-lengths. It is claimed by some that damage done to the retina is due to these rays. However, this paper, in dealing with screens for absorbing ultra-violet radiation and for reducing the intrinsic brightness, is not primarily concerned with the actual transmission of the eye media, chiefly because of the lack of knowledge regarding the exact rays that are harmful. Owing to the scanty knowledge on this subject it is well to protect the eyes from excessive ultra-violet radiation as is encountered in certain industrial processes such as arc and oxyacetylene welding, and many other processes in the steel industries, as well as in the special uses of sources rich in ultra-violet radiation in photography, medical practise, etc. No attempt will be made to prescribe glasses for all cases but data and experiences which have accumulated will be recorded.

TRANSPARENCY OF VARIOUS MEDIA.

There are several means of studying the transparency of media for invisible ultra-violet rays. The method which will be found most readily applicable in many cases is that of photography. A spectrograph with a quartz optical system affords a simple means of roughly determining the transmission of any medium. However, when the transmission is to be accurately determined the photographic method is a very tedious procedure. The photographic action is determined by the density of the plate. In plotting the density against the logarithm of the illumination a straight line relation is found over a certain range of illumination. This straight line region is taken as the region of correct exposure. By no means is the density of the silver deposit proportional to the logarithm of the intensity of radiation throughout any extremely wide range of illumination. Further, rays of various wave-lengths show different relations between density of the silver deposit and the illumination. These relations should be determined for various standard wave-lengths.

The procedure adopted by the writer is briefly as follows.

The light of a quartz mercury arc reflected from a magnesia block, was used as a source of ultra-violet radiation. Its spectrum was formed by a small quartz spectrograph, the slit being wide enough to furnish bands from each ultra-violet line of sufficient width for photometering. A series of exposures was made, of equal length, but with different known illuminations of the magnesia surface. Following these, exposures of the same length were made through the media to be examined, with known illumination. The photographs were measured for density on a Marten's polarization photometer and curves were plotted be-

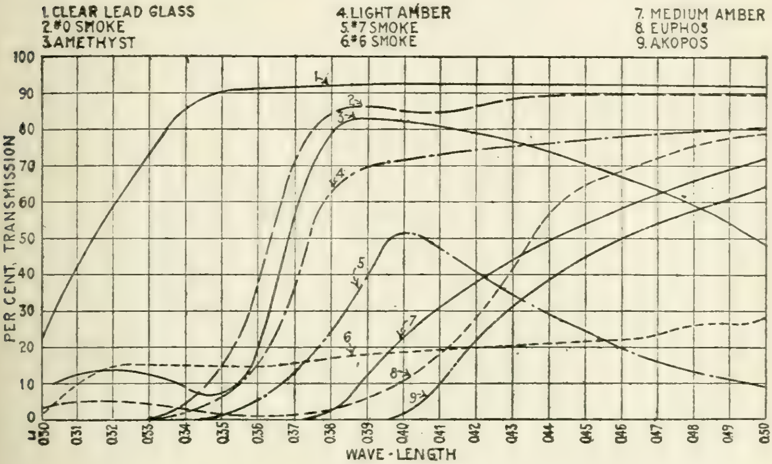


Fig. 1.

tween density and illumination for each line. From these curves the corresponding intensities of illumination (*i. e.*, transmission) were read off for each line of each negative exposed through the specimens. By taking into account the relative illuminations of the magnesia block, the transmission at each wave-length was readily obtained. The same method could be applied to a determination of the relative intensities of the various ultra-violet rays of any illuminants.

In Fig. 1 are shown the transmission curves of various representative glasses. Only the short-wave end of the spectrum has been considered here. It will be noted that the transparency of

clear lead glass remains unchanged to rays as short as 0.35 μ when it begins to absorb, becoming opaque to rays somewhat shorter than 0.30 μ. The smoke glasses are representative of many examined. They show little tendency to selectively absorb ultra-violet rays and differ considerably in their characteristics. These glasses cannot conscientiously be recommended with safety for the protection of the eyes against excessive ultra-violet radiation. The amethyst glass absorbs more ultra-violet rays than clear glass yet is transparent far into the ultra-violet region. The amber glasses quite satisfactorily absorb ultra-violet rays but gives rise to some objection from the standpoint of color. Several deep red glasses were examined and all were found to be opaque to ultra-violet rays but on account the strong color should not be recommended except in very special cases. The transmission of Euphos glass decreases considerably in the ultra-violet but shows a tendency to increase in transparency in the region of 0.32 μ. This transparency to short-wave ultra-violet rays becomes quite marked in less dense specimens. The most satisfactory glass yet examined from several standpoints is the Akopos specimen. Its color is a light yellowish-green and samples showing but little objectionable color are quite effective in absorbing ultra-violet rays. The color of this glass is preferable to amber for various reasons which will be considered later. None of the colorless glasses examined has been found to absorb all the ultra-violet rays which are considered as possibly harmful.

SPECTROGRAMS.

Owing to the absence of collected data upon this subject it seems of interest to show a number of spectrograms illustrating the transparency of various media to rays of different wavelength. For this purpose a mercury arc is well suited owing to its constancy. A source giving a continuous spectrum is more desirable but such a source emitting considerable ultra-violet radiation is unavailable. The iron arc is often used but is used by the writer only in special cases. The quartz mercury arc on account of its constancy is well suited for obtaining qualitative data for rough comparison and under certain conditions can be used successfully in obtaining accurate transmission data.

The spectrograms are divided into groups headed in all cases, excepting Group A, by the spectrum of the unobstructed light of the illuminant used in each particular group. The spectrograms are numbered consecutively for further convenience and the exposure times are given in order to roughly indicate the transparency of each specimen. In the last column are given the transmission coefficients of the specimens for the total visible light from a tungsten lamp operating at 1.25 watts per candle or at a temperature approximately 2,030° C or 3,700° F.

In Group A is shown the spectrum of the iron arc. The other spectrograms in the same group with the exception of 6, which is that of the carbon arc, were obtained with a carbon-iron arc. The carbon and iron electrodes were interchanged in position and reversed in polarity as noted. As is to be expected when the iron is positive the light is richer in ultra-violet rays as is shown in 2 and 4.

In Group B are shown the spectrograms through two smoke glasses that were proposed for use in arc welding; 8 and 9 show the great difference in transparency of these glasses to ultra-violet rays. Of course their transparency to visible light differ very much but smoke glasses are found to have very different characteristics and their transparency to visible light is no safe criterion in estimating their value in absorbing ultra-violet rays. Their peculiarities are emphasized in 32 which is a very dense smoke. Ths glass is more transparent to rays near 0.360 μ in wave-length than to the violet rays. Smoke glasses are also considered in other groups.

Euphos glass which has received some attention in the past is seen in 38 and 47 to be transparent to ultra-violet rays of rather short wave length. The amber and Akopos specimens do not show such transparency to the shorter ultra-violet rays even after prolonged exposure of the photographic plate.

In Group I and J are the spectrograms illustrating the transparency of various common glasses which are often used in the industries. It is seen that the cobalt-blue glass is more transparent to ultra-violet radiation than a clear glass of the same thickness. The clear glass used was a lantern-slide cover glass. This difference is best shown in 60 and 61 where the exposures

were equal. It is significant to note that the clear glass is approximately 46 times more transparent to visible light than the cobalt-blue glass. The light colored gelatine films used on the stage show a high degree of transparency to ultra-violet rays. Of course they are generally used with glass optical systems which considerably decreases the possibility of injury to the eye.

No detailed discussion of the spectrograms will be entered upon because the information it is desired to present accompanies the photographs. On combining the exposure time and the transparency to visible light with an inspection of the various spectrograms interesting comparisons can be made.

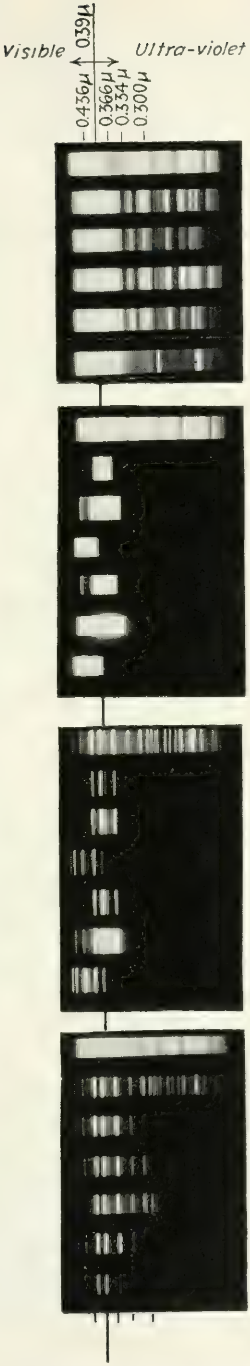
SPECIAL SCREENS.

A few special screens may be of interest. Yellow screens are often used in correcting photographic plates to give true values. The screens may also be used for visual purposes. In Group M a number of yellow screens made by flowing the gelatine containing the dye upon plate glass. The total glass is about ¼ inch (6.35 mm.) thick. The screens are of approximately the same transparency to visible tungsten light and are very closely of the same color. It is noted that three of them transmit some deep violet and ultra-violet rays while the other three absorb all energy of shorter wave-length than about 0.470 μ.

In Group N are shown some special screens devised for the purpose of transmitting ultra-violet for special uses; 81 and 82 show the effect of combining certain aniline dyes; 83 is a purchased screen whose composition is unknown to the writer. It was intended to transmit only ultra-violet rays, but it does not absorb all the visible rays that are photo-chemically active on the plate used. When combined with aniline green it is quite satisfactory as shown in 84. The green dyes, 81 nd 82, transmit some ultra-violet and thereby differ from that shown at 85. The results of prolonged exposures with the acid green and ethyl violet combination are shown at 86 and 87.

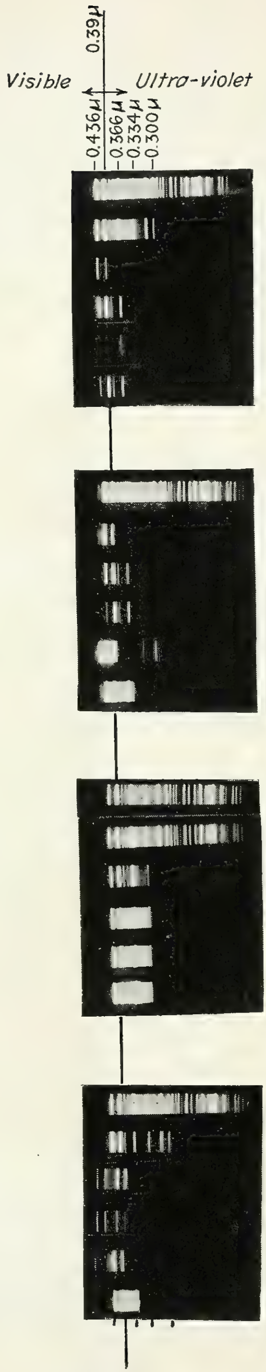
A dye famed for its absorption of ultra-violet rays is esculine (88). It is highly transparent to visible rays and fluoresces a faint blue under ultra-violet rays.

A dye which has been proposed for the purpose of trans-



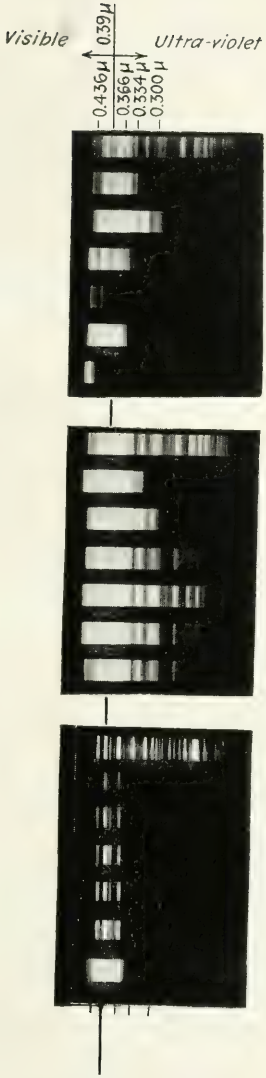
	Exposure (Seed's 23) sec.	Transmission coefficient of specimen for tungsten light at 1.25 w.p.c.
Group A.		
1. Iron arc (bare)	½	
2. Iron carbon arc { Iron above / Iron positive }	½	
3. Iron carbon arc { Iron above / Iron negative }	½	
4. Iron carbon arc { Iron below / Iron positive }	½	
5. Iron carbon arc { Iron below / Iron negative }	½	
6. Carbon arc	½	
Group B.		
7. Iron arc (bare)	½	
8. Oxy-acetylene welders, K	3	0.002
9. Smoke, No. 8 shade	3	0.04
10. Akopos	3	0.50
11. Oxy-acetylene welders, K	10	0.002
12. Smoke, No. 8 shade	10	0.04
13. Akopos	10	0.50
Group C.		
14. Quartz mercury arc	½	
15. Oxy-acetylene welders, K	3	0.002
16. Smoke, No. 8 shade	3	0.04
17. Akopos	3	0.50
18. Oxy-acetylene welders, K	10	0.002
19. Smoke, No. 8 shade	10	0.04
20. Akopos	10	0.50
Group D.		
21. Iron arc (bare)	½	
22. Quartz mercury arc	½	
23. Fieuzal, light	½	0.86
24. Clear glass	½	0.92
25. Cobalt blue, dense	2	0.02
26. Celluloid	1	0.60
27. Signal green, medium	2	0.001

Plate I.



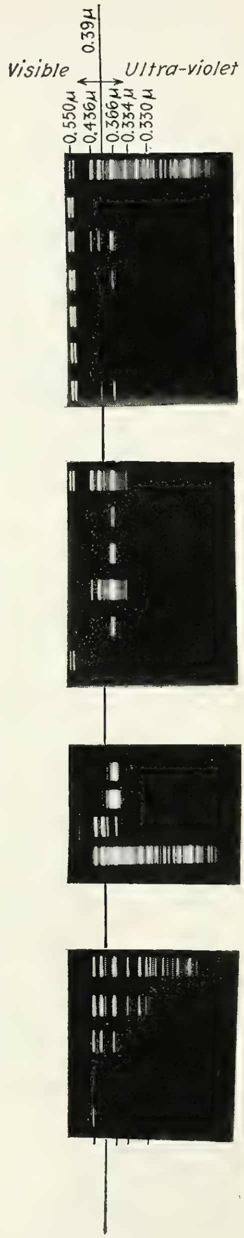
	Exposure (Lantern slide plate) sec.	Transmission coefficient of specimen for tungsten light at 1.25 w.p.c.
Group E.		
28. Quartz mercury arc	½	
29. Clear glass, 1/16″ thick ..	½	0.92
30. Amber, medium, X.....	4	c.50
31. Kosma	1	0.83
32. Electric smoke	480	0+
33. Smoke X	3	0.015
Group F.		
34. Quartz mercury arc	½	
35. Amber, medium, X.....	15	0.50
36. Kosma	½	0.83
37. Smoke X	6	0.015
38. Euphos, 3/64″ thick	8	0.81
39. Thermoscopic	1	0.86
Group G.		
40. Quartz mercury arc	½	
41. Distilled water (1 cm.) ..	½	0.93
42. Clear glass, 1/16″ thick ..	½	0.92
43. Smoke A	1½	0.36
44. Smoke C..............	2½	0.20
45. Smoke A + C..........	7	0.07
Group H.		
46. Quartz mercury arc	½	
47. Euphos, 1/64″ thick	1	0.90
48. Amber, light shade.....	3	0.67
49. Amber, medium shade ..	6	0.45
50. Amber, medium, X.....	20	0.50
51. Smoke X	15	0.015

Plate II.



	Exposure (Seed's 23) sec.	Transmission coefficient of specimen for tungsten light at 1.25 w.p.c.
Group I.		
52. Iron arc (bare)	½	
53. Clear glass, $^{1}/_{16}''$ thick ..	½	0.92
54. Cobalt blue, dense	2	0.02
55. Canary, light	2	0.82
56. Signal green, medium ..	8	0.001
57. Signal blue, medium ...	4	0.11
58. Green, dense...........	8	0.20
Group J.		
59. Iron arc (bare)	½	
60. Clear glass	2	0.92
61. Cobalt blue, dense	2	0.02
62. Gelatine film, purple ...	2	0.17
63. Gelatine film, blue.....	2	0.43
64. Gelatine film, green....	2	0.67
65. Gelatine film, orange...	2	0.53
Group K.	Lantern Slide	
66. Quartz mercury arc	½	
67. Smoke CK.............	2	0.001
68. Smoke CK.............	10	0.001
69. Smoke CK.............	20	0.001
70. Smoke DK.............	1	0.15
71. Smoke DK.............	2	0.15
72. Smoke DK.............	5	0.15

Plate III.



	Exposure (Cramer spectrum sec.	Transmission coefficient of specimen for tungsten light at 1.25 w.p.c.
Group M.		
73. Quartz mercury arc·······	½	
74. Aurantia·················	2	0.44
75. Orange G·················	2	0.54
76. Uranin···················	2	0.54
77. Tartrazine··········	2	0.57
78. Fluorescin···············	2	0.51
79. Aniline yellow···········	2	0.52
Group N.	(Cramer spectrum)	
80. Quartz mercury arc (glass)	½	
81. Aniline green + resorcine blue···········	20	0+
82. Acid green + ethyl violet··	20	0+
83. Ultra-violet screen········	5	0.001
84. U. V. screen + aniline green	20	0+
85. Napthol green············	2	0.04
Group O.	(Lantern slide	
86. Acid green + ethyl violet··	120	0+
87. Acid green + ethyl violet··	300	0+
88. Esculine·················	½	0.87
89. Quartz mercury arc········	½	
Group P.	(Lantern slide)	Thickness of aqueous solution cm.
90. Nitrosodimenthylaniline ··	½	0.01
91. (Various depths contained	2	0.2
92. in a quartz cell	9	0.5
94. ······························	30	1.0
95. ······························	90	1.0

Plate IV.

mitting only ultra-violet rays is nitrosodimenthylaniline. Group P shows the results obtained with an aqueous solution of this substance of various depths. These spectrograms show at least that the aqueous solution is not highly satisfactory for this purpose.

GOGGLES IN THE INDUSTRIES.

While goggles have long been recommended in the industries they have received special attention since the inauguration of the "Safety First" movement. The indifference and bias of the workman are factors which must be considered in prescribing goggles for the various processes. Of course the conditions found in any particular case are the determining factors in prescribing goggles. In processes where excessive heat is encountered the goggle must have no metal parts touching the skin. In any case the lens must have sufficient mechanical strength, it must absorb the ultra-violet rays in cases where these are encountered in excessive amounts, it must be of sufficient density to reduce the retinal image to a safe brightness, and it should be as free from color as possible. If colored it is preferable that it be of a color that will not distort colors to any great extent.

Owing to the many processes found in the steel industry a brief account of experiences in studying the conditions accompanying the various processes and the requirements of glasses for the protection of the eyes, should be of interest. In those cases where mere grinding or chipping was done clear thick lenses in metal screens are of course satisfactory. In all processes involving high temperatures it seemed advisable to prescribe glasses which eliminated ultra-violet rays. This simplified the matter for such a glass as Akopos would be satisfactory and could be adopted as a standard. With this glass could be combined any shade of satisfactory neutral tint glass, its density depending upon the process involved and the amount of moving about required of the workman. For arc welding a very dense neutral tint glass combined with Akopos (a yellow-green glass) was recommended. For the oxyacetylene and oxyhydrogen welding processes a somewhat lighter shade of neutral tint glass was used. The shade of neutral tint glass necessary of course is still lighter for the processes merely involving molten iron and steel,

varying in density approximately with the temperature involved. Great advantage was of course experienced by actually consulting the workman. An interesting case was encountered in the lap-welding process. Here the welder judges the correct temperature visually. While the temperature is not extremely high it seemed advisable to suggest the use of glasses which absorb th ultra-violet rays quite effectively. The amber and Akopos were the only specimens at hand which answered this purpose. The welder was quite at a loss in judging temperatures through the amber glasses; however, he became enthusiastic over the results obtained with the yellow-green glass claiming that he suffered no difficulty whatever. This brings to mind the fact that through a yellow-green glass transmitting only a limited region of the spectrum the relation of intensity and temperature appears practically the same as to the unobstructed eye when the luminous substance radiates light approximately the same as a black or a gray body. Years ago Crova suggested a method of photometry involving this principle. The Akopos has a maximum of transmission at 0.550 μ where hue changes slowly with the wave-length; that is, where hue sensitivity is low. Further a yellow-green glass only absorbs light at the extremes of the spectrum, thus in general distorting colors to a less degree than glass of any other color. These facts point more favorably to the use of a light shade of yellow-green glass than an amber glass. In an industry involving many processes such as the steel industry it appears to simplify matters and to assure safety if a glass which absorbs ultra-violet and which is satisfactory and inconspicuous in color is used universally in processes where hot metal is encountered, combining with this in each particular case a neutral tint glass of proper density to decrease the brightness of the retinal image to a safe degree. This procedure insures protection to the workman at all times.

SUMMARY.

The problem of eye protection in processes involving high temperatures and excessive amounts of ultra-violet radiation must be considered from two standpoints. The ultra-violet radiation must be screened from the eye and the retinal image must be reduced to safe brightness.

The exact ultra-violet rays that are active in destroying animal tissue and causing irritation are not known. It is known that the rays of extremely short wave-length which are not transmitted by ordinary clear glass are harmful. Whether any rays of longer wave-length than 0.300 μ are harmful is a problem yet to be solved. In the absence of such knowledge it is safe to protect the eyes against all the ultra-violet rays in many industrial processes such as arc welding.

No neutral tint glass was found which would absorb all the ultra-violet rays. Therefore a simplified scheme is found in adopting a glass which does eliminate these rays and combining with it where necessary a neutral tint glass of such density that the retinal image is reduced to a safe brightness.

Transmission curves for short-wave radiation are shown for various representative glasses.

Spectrograms showing the transmission of various media for the short-wave radiation from the quartz mercury arc and the iron arc are presented, also the exposure times and transmission coefficients for visible tungsten light for the purpose of rough comparison.

A number of spectrograms are presented which show the transmission of screens useful for special purposes. Some are intended to absorb the ultra-violet rays, others are intended to transmit only the ultra-violet rays. These are chiefly for photographic purposes but are of value in other processes.

A brief account is given of experience with goggles and glasses in the industries.

As no neutral tint glass was found which totally absorbed the ultra-violet, a yellow-green glass was chosen as most desirable for several reasons. It was found that workmen in welding processes preferred this glass to any other color. They successfully used this at once while condemning amber glasses very heartily. Colors are distorted less through this glass than through glass of any other color. Another significant fact is that the relation of the temperature and luminosity for black or gray bodies is practically the same through a yellow-green glass as to the unobstructed eye.

These data are presented because of increased demand for

such knowledge having been obtained largely on account of requests for examination of glasses and investigation of actual conditions found in industrial processes. Of course glasses should be tested at least by means of a spectrograph before adoption, but the data presented indicate the limitations and advantages of the various representative glasses and furnish some information gleaned from experience.

No bibliography of the subject is given because it is understood that the Research Committee of this society has prepared an elaborate one* for publication.

DISCUSSION.

Dr. William Churchill: I was asked to contribute a few words to the discussion and am glad to do so for the reason that I appreciate the work that has been done by Mr. Luckiesh in getting these data together and presenting them in such interesting form.

Much has been heard of this question of colored glasses for optical purposes in the past few years and I think we have all felt, more and more, that there was a large amount of work remaining to be done by some one in putting the subject of colored glasses for optical use on a thoroughly satisfactory scientific basis. I had the pleasure in September, 1907, of being present in Dresden when a paper was presented by Drs. Schanz and Stockhausen, who deserve credit for having largely emphasized the importance of glasses which absorb the ultra-violet radiations. One of the authors of the papers (I do not recall which) was an electrical engineer and the other an ophthalmologist. The electrical engineer had been doing work on arc lights a year or two previously which had injured his eyesight and he had made up his mind to find something to meet such a situation in the future. The authors called attention, as Mr. Luckiesh has to-night, to the transmission of ultra-violet light by various glasses and then brought forward what they had christened Euphos glass. Since that time there have appeared quite a large number of glasses, which we glass manufacturers classify as more or less similar to Euphos.

I note in running through Mr. Luckiesh's data, that the speci-

*Trans. I. E. S., Vol. IX, No. 3, p. 311.

mens of Euphos glass tested were lighter in tint than the Akopos, and Mr. Luckiesh seems to have reached the conclusion that the Akopos is different from the Euphos. It is commonly understood among glass manufacturers that there is not much difference, and we have supposed that Akopos was a trade name for a rather dark shade of the Euphos. In one case cited by Mr. Luckiesh the Euphos glass is shown to have a transmission coefficient of 0.90 and in another case about 0.80. Five grades of Euphos are usually offered for sale, and the two shown here, I should think, would correspond to numbers one and two, while one which has a coefficient of about 0.50 would correspond to the Akopos and is known as number four.

Mr. Luckiesh states, "None of the colorless glasses examined has been found to absorb all the ultra-violet rays which are considered as possibly harmful." I have here a sample of a special glass recently developed and almost colorless with only a faint yellowish tinge, so slight as to be hardly noticed. It absorbs all of the ultra-violet and gives almost total transmission in the visible spectrum. I have another glass, a very pale yellow, which possesses certain properties more or less unique. It absorbs all of the ultraviolet and at the same time all of the violet and blue and transmits practically unimpared the red, yellow and green, the absorption in the visible spectrum being about 15 per cent. In this glass we have total absorption in the blue, violet and ultra-violet, with almost total transmission in the balance of the spectrum.

In this connection, I might say that what study we have been able to make of different glasses for special optical purposes, has led us to believe that the most successful glasses will be found among these, which show a very sharp absorption—what we call a sharp "cut-off"—instead of a gradual absorption, such as is characteristic of all glasses of the Euphos type. There are many advantages from a practical point of view in having such an absorption as it gives one a much more definite control of the problem.

Perhaps one more glass will be of interest while we are on this subject. I show it as it is typical of another kind of glass which is quite useful in protecting the eyes in electrical welding and furnace work. This glass absorbs all the violet and blue and absorbs the extreme red about equally well, so the spectrum

is narrowed down to yellow, with green on one side and some red on the other. It reduces the intensity considerably, but cuts out the harmful wave-lengths at both ends of the spectrum.

The real question at issue seems to have been stated practically by Mr. Luckiesh in calling attention to the absorption of energy in the eye. It seems to be important to keep the eye "cool" by protecting it from infra-red and ultra-violet. These glasses which I have shown may aid in indicating that it is now possible to furnish the ophthalmologist quite a wide variety from which to choose. Just such work as Mr. Luckiesh has been doing goes a long way toward putting the question of protective glasses for optical use on a firm scientific basis. It is to be hoped that it will not be long before this subject receives the wide attention which it deserves.

Mr. M. Luckiesh (Communicated in reply): The object of my paper is to bring forth in condensed form the transmission characteristics of many glasses for short-wave energy and to relate experiences met with in studying in a practical manner the protection of the workman's eyes in industrial processes. Many samples of glass were obtained with more or less difficulty but by no means is it thought that all the desirable glasses have been studied. Dr. Churchill brings to my attention some glasses of a pale yellow color which he states absorb all the ultra-violet rays. If it is possible to obtain coloring elements which have very sharp absorption bands at the short-wave end of the spectrum then colorless glasses can be made which cut off all the ultra-violet rays. Coloring elements vary in the sharpness of their absorption bands, but I am aware of none which would answer the foregoing requirement. I do not believe any harmful effects arise from a moderate amount of ultra-violet radiation of wave-lengths near the visible region because energy of these wave-lengths is present in daylight in large amounts. However, in recommending glasses for industrial processes such as arc welding it has been considered advisable in order to insure safety to recommend a glass which absorbed absolutely all of the ultra-violet rays. Through the kindness of Dr. Churchill I have been able to examine one of the glasses which he exhibited and while it did not absorb all of the ultra-violet

rays it transmitted only a relatively small amount near the visible region. The thickness of the sample, however, was greater than could be used in protective glasses. At ordinary lens thickness it would require greater depth of color to meet the requirements I have imposed. The glass, being a pale yellow, is very desirable from the standpoint of color.

As Dr. Churchill has noted my samples of Euphos were more transparent than the sample of Akopos. The thinner sample of Euphos was taken from an incandescent lamp bulb it having been used by a lamp manufacturer for the absorption of ultra-violet rays. This appears to the writer as a needless precaution considering the much greater amounts of ultra-violet radiation in daylight than in incandescent tungsten light and the excessively greater intensities of daylight ordinarily encountered. It is quite likely that a denser specimen of Euphos would be as effective as the Akopos sample in absorbing ultra-violet rays.

I have not especially treated the protection of the eyes from infra-red rays in this paper because the industrial processes considered are more dangerous owing to ultra-violet radiation. It is an established fact that ultra-violet radiation in excessive amounts (especially energy of very short wavelengths) is very harmful. However, there is no absolute proof that infra-red rays in moderate amounts are harmful although there is a growing opinion that cataract is due to the absorption of energy. If this be true, cataract should be quite common among iron-workers and others working with glowing materials.

Practically no energy of longer wave-lengths than 1.4 can reach the eye lens. I have treated this subject in a paper on "Radiant Energy and the Eye,"* and in another paper as yet unpublished. The object as shown in these papers is to ascertain the amount of energy absorbed in the eye media and the energy density for glowing bodies at various brightnesses or temperatures. However, as the long-wave energy is of no benefit to vision a protective glass should not transmit this radiation too freely in order to be on the safe side. It is quite likely that absorption of energy in the eye lens is not alone responsible for cataract. An impoverished condition or absence of a protective agent are probable allied causes of cataract.

* *Electrical World*, Oct., 25, 1913.

TYPES OF SIGNAL LENSES.*

BY H. P. GAGE.

Synopsis: This paper describes some of the types of signal lenses in common use, and some special forms recently invented, and presents the results of photometric experiments made in the laboratory, together with comments on how these results may be of use in designing a signal system. To illustrate the appearance of a signal as seen under different conditions, sets of photographs were made showing the lenses as viewed directly and when turned to one side through different angles. The measured photometric value for each lens position was marked in order to connect the appearance with the corresponding photometric measurements.

1. THE OPTICS OF SIGNAL LENSES.

The lenses used for railway signal purposes are of the general form illustrated in Figs. 1, 6, and 7 which sum up the development of such lenses from the old plano-convex type called a "bullseye" to the modern forms. In general, these lenses are designed so that the light spreading out from the point source will be bent so as to be projected into a narrow, nearly parallel beam of light. Recently, however, it has been found that for some purposes a narrow beam of light is not as desirable as a more spreading beam such as can be secured by what is known as the "wide angle" lens or by a "spredlite" lens. In this paper I shall describe the main features of these types of lenses.

The widely used optical or smooth face type of lens has the corrugations on the inside and has a smooth outer face which prevents the lodgement of snow and dirt. Since all actual light sources are more or less extended, the beam of light coming from this optical lens will have a certain amount of spread, as is shown in Figs. 2 and 4 (b). Fig. 3 shows that while most of the light from the source strikes the steps of the corrugations and is pro-

* A paper read at a meeting of the Chicago Section of the Illuminating Engineering Society, April 10, 1914.

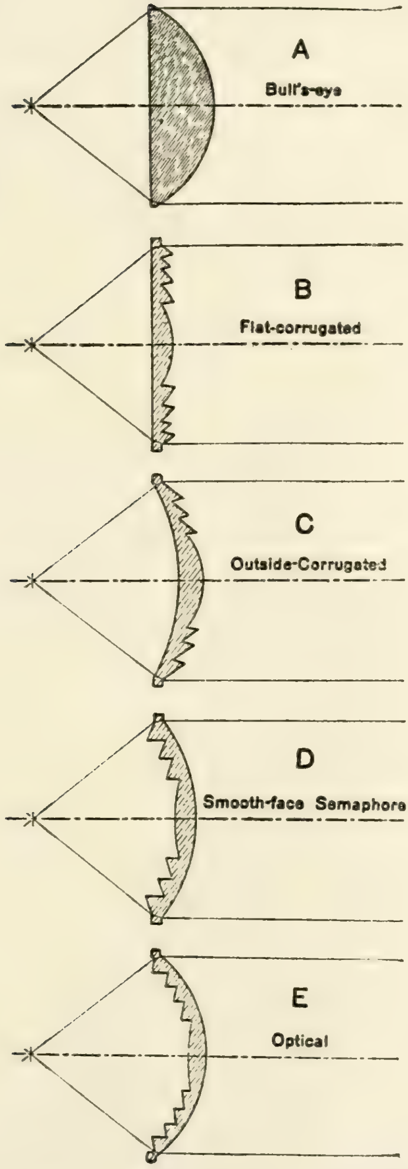


Fig. 1.—Steps in the evolution of the modern signal lens.

jected forward, a certain amount strikes the risers of the steps, is deflected to one side and lost.

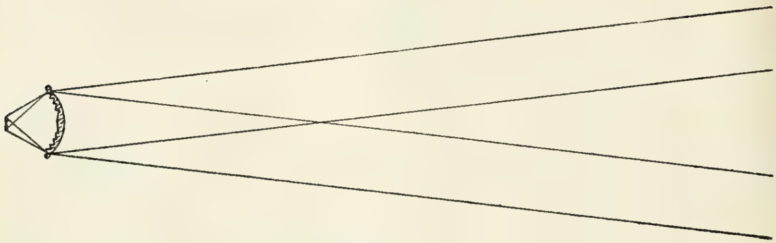


Fig. 2.—Diagram showing the diverging rays when an extended source is used with an optical lens.

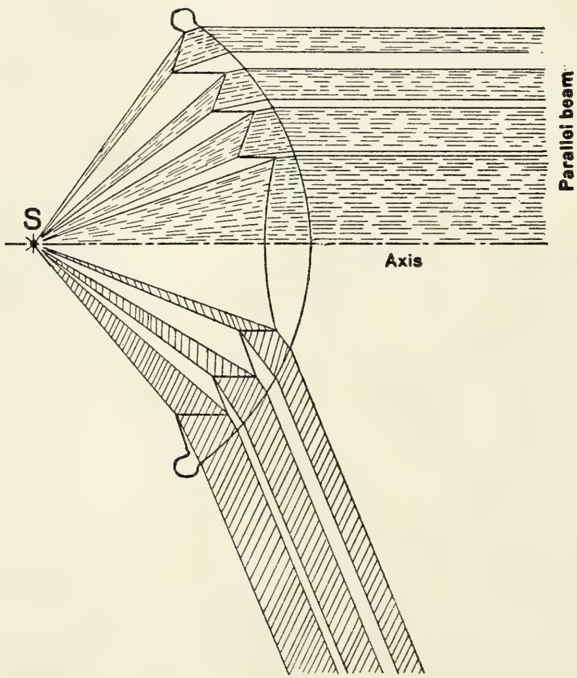
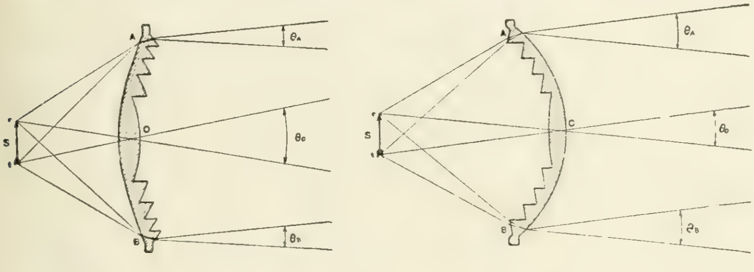


Fig. 3.—Path of light through an "optical" type lens. The upper half of the figure shows the course of the light which strikes the zones and emerges parallel to the axis and the lower half of the figure shows the course of the light which strikes the risers and is deflected to one side.

The inverted type is a lens, Fig. 6 (F), designed with the smooth convex face inside and the corrugations outside. It

bulges in somewhat toward the flame and consequently the center of the lens has a shorter focal length and a greater spread, as is illustrated in Fig. 4 (a). There is no light lost on the risers, as a ray which just misses one step gets through the next



A B

Fig. 4.—Course of light rays from an extended source through an inverted lens A and an optical lens B. Note the greater angle of spread θ_0 with the inverted lens.

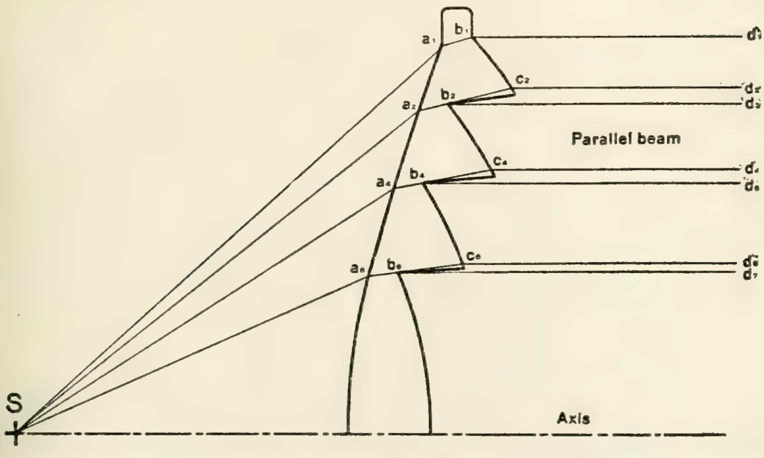


Fig. 5.—Course of light rays through an inverted lens, showing that no light is deflected to one side by the risers.

(Fig. 5). Such a lens may be provided with a cover glass, Fig. 6 (B), and thus presents smooth, easily cleaned surfaces, both inside and out. The air space between the lens and the cover glass prevents the frosting of the lenses in extreme cold weather. The intensity of the light projected by these two types of lenses is for all practical purposes the same, except that, when the inverted type lens is used with a cover glass, the cover glass

absorbs approximately 15 per cent. of the light. It must be remembered, however, that if it is easy to clean the inner surface of a lens it will be kept clean, and under service conditions this will more than compensate for the 15 per cent. loss of light due to the cover glass.

Wide angle or spredlite lenses may be of either the smooth face or the inverted type. The wide angle lens, Fig. 7, is designd to set into the standard signal lamps at the usual distance from the flame, *i. e.,* 3½ inches (8.89 cm.) in the case of the 5⅜-inch (13.65 cm.) lenses. Set at this distance, the lens is designed so that the light after passing through the lens will diverge over an angle of about 17 degrees; this allows the signal to be seen over a greater angle, but of course it shows considerable reduction of intensity, compared to the optical lens.

The spredlite lens is of similar design to the optical or inverted lens, except for panels or flutings on the smooth face. These flutings do not alter the course of the rays in one meridian, but they do spread the light in a meridian at right angles to the axis of the flutings. For example, with the flutings set in a vertical direction, the result is a fan shaped beam of light with a narrow vertical spread, and a wide horizontal spread. Such a lens gives a much higher intensity than a wide angle lens having the same horizontal spread and should prove especially useful on curves. Many other types of lenses have been developed for special purposes, but those just mentioned are the most important types in railroad service.

2. LIGHT SOURCES.

In railway signal service, the light sources used are kerosene flames (the long-time burner, and the one-day burner), acetylene flames, and incandescent lamps. Tungsten lamps of 1 or 2 candle-power are coming into considerable use.

The long-time burner illustrated in Fig. 8 shows the flame photographed natural size by the side of a centimeter scale. This flame when set to give 1 candle-power has a height of 0.35-inch (0.89 cm.), a width of 0.512-inch (1.30 cm.) and an intrinsic brilliancy of 0.8 candle-power per square centimeter.

The one-day burner illustrated in Fig. 9 has a height of 0.59-

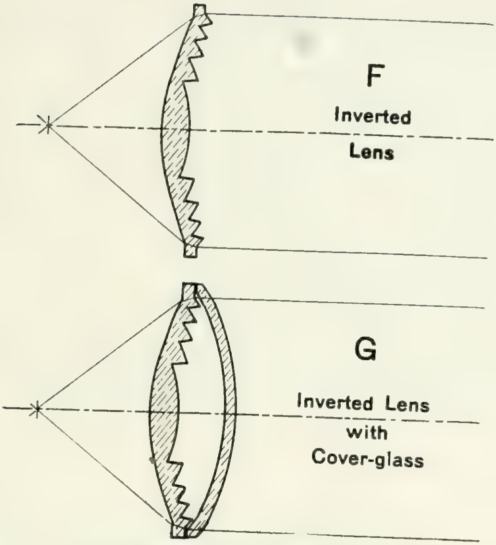


Fig. 6.—F, inverted lens; G, inverted lens with cover-glass.

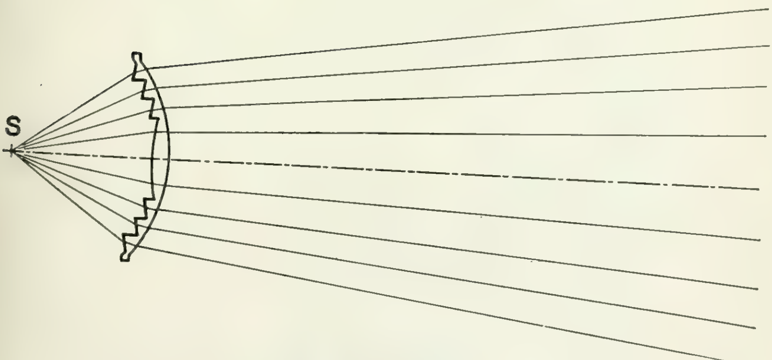


Fig. 7.—Wide angle lens.

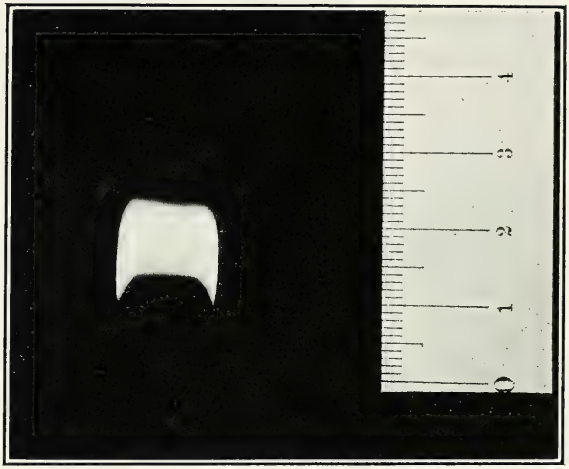


Fig. 8.—Natural size of the flame of a long-time burner, set for 1 candle-power.

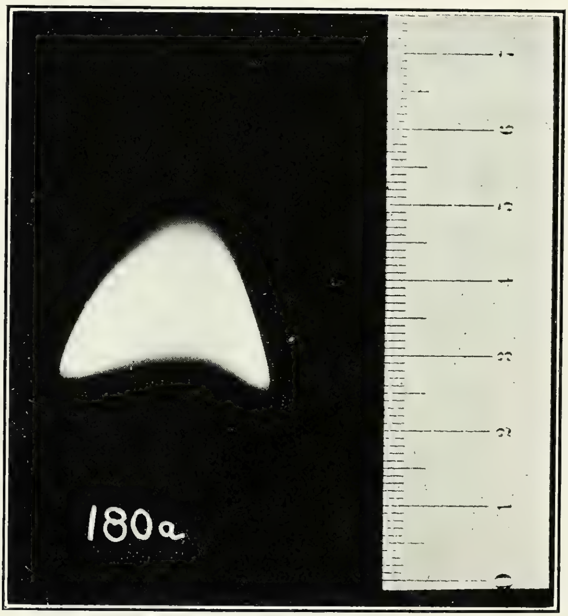


Fig. 9.—Natural size of the flame of a one-day burner set to give 2 candle-power.

inch (1.5 cm.); a width of 1.1-inch (2.78 cm.), when set to give 2 candle-power. The average intrinsic brilliancy is less than that of the long-time burner, being 0.65 candle-power per square centimeter.

3. METHODS OF TESTING.

In order to reduce all the different sizes of lenses to a common basis, a standard source of light was used. A milk glass screen, Fig. 10, 1-inch (2.54 cm.) in diameter, was illuminated by a 60-watt tungsten lamp and used in place of a kerosene flame. This gives a perfectly uniform source of light of definite size independent of weather conditions and other slight variations. In general, the results of this test show that the equivalent beam candle-power obtainable with a lens of a given size is directly proportional to its area. This is modified by the fact that the dark rings seen in any lens are more prominent with relatively short focus lenses than with long focus lenses, hence short focus lenses give lower axial candle-power than long focus lenses of the same diameter. The use of this source of definite size enables us to determine for each lens what spread is obtainable with a 1-inch (2.54 cm.) source, and from this value we can calculate what the spread is with any source of known dimensions. With the kerosene flames above described, the intensity of the beam was measured by the usual methods employed in photometry. To determine the spread of the beam the photometer was set to indicate one-half the axial intensity; for example, if the lens showed 64 candle-power along the axis, the photometer was set to read 32 candle-power. The lens was then turned to one side until the photometer balance was obtained, then it was turned to the other side until the photometer balance was again obtained. In each case, the position of the lens was read on a graduated circle. We thus obtained the angle between the two directions in which the beam has 50 per cent. of the axial intensity. This was recorded as the spread of 50 per cent. intensity for the given lens and flame. The lens was then observed directly from the position of the photometer box and the lens again turned until the two extreme positions at which fairly good signal indications could be obtained were noted. The angle between these

two positions was recorded as the extreme spread. The exact limit of the extreme spread is, of course, largely a matter of individual judgment, but the figures give a fair estimate of the angle covered.

TABLE I.—DATA FOR OPTICAL LENSES.

A	B	C	D	E	F	G	H
		With long-time burner			With one-day burner		
			Spread, ft. per 100			Spread, ft. per 100	
Diameter inches	Focus inches	Candle-power	Of 50 per cent. intensity	Extreme	Candle-power	Of 50 per cent. intensity	Extreme
4	2¾	37.5	14.0	16.6	30.6	24.3	26.7
4	3½	40.5	12.2	14.4	32.8	21.0	23.3
4⅛	2¾	39.6	15.2	17.4	32.3	25.5	28.1
4⅛	3½	42.0	12.5	14.7	33.5	21.5	23.7
4½	3	44.5	12.9	15.3	36.3	22.3	24.7
4½	3½	48.0	11.9	14.1	38.5	20.6	22.7
5	3½	57.0	11.7	13.8	46.5	20.2	22.3
5⅜	3½	69.0	11.75	14.0	56.2	20.4	22.6
6	3¾	82.0	10.6	12.6	67.1	18.4	20.3
6⅜	3¾	90.5	10.5	12.4	74.2	18.1	20.0
8⅜	4	130.0	8.4	11.7	106.5	14.6	20.2
8⅜	5	142.0	7.4	8.7	116.0	12.7	14.0

TABLE II.—DATA FOR INVERTED LENSES.

A	B	C	D	E	F	G	H
		With long-time burner			With one-day burner		
			Spread, ft. per 100			Spread, ft. per 100	
Diameter inches	Focus inches	Candle-power	Of 50 per cent. intensity	Extreme	Candle-power	Of 50 per cent. intensity	Extreme
4	3½	35.4	14.5	17.5	29.0	24.0	31.0
4⅛	2¾	42.0	17.0	21.1	34.2	28.0	38.3
4½	3	51.8	16.1	19.8	42.3	26.4	35.7
5	3½	62.5	14.2	17.75	51.0	23.4	32.1
5⅜	2¼	59.0	17.0	19.3	48.0	28.0	53.0
5⅜	3½	66.8	13.8	16.75	55.3	22.7	30.3
6⅜	3¾	89.8	12.7	16.5	73.2	20.8	29.6
7⅜	3	94.5	13.5	23.7	77.1	22.3	42.8
8⅜	3½	120.0	11.8	19.8	97.8	19.5	35.7

For practical purposes the photographic method of testing has proven of great value. This is illustrated in Figs. 12 and 13, which are half-tone reproductions of a series of photographs made of signal lenses, provided with kerosene flames. Three lenses were set up on a rotating table and very carefully adjusted

until the axis of each pointed toward the camera objective, Fig. 11 (A); a photograph was then taken in this position. The three lenses were then rotated to one side by turning the top of the table to an angle, Fig. 11 (B), when another photograph was taken, and so on. Prints of these photographs were then

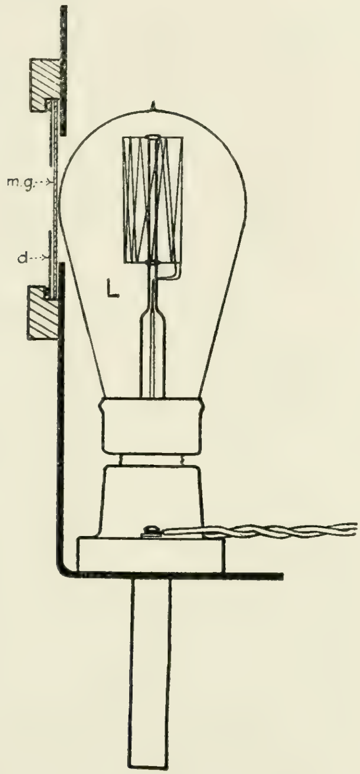


Fig. 10.—Standard source; d, tin diaphragm with round hole one inch in diameter; m.g., milk glass; L, 60-watt tungsten lamp.

mounted on a card and labelled as shown. The candle-power values were obtained later by measurements on a photometer. The photographs show at the same time the photometric value and the appearance when a lens is viewed directly from different directions.

4. RESULTS OF TESTS.

In Table I is shown the results of the tests of the optical type lens. Column A gives the outside diameter of the lens, column B gives the distance from the edge of the lens to the flame or focus, columns C, D and E refer to the tests made with the long-time burner and columns F, G, and H refer to the results of the one-day burner. Column C is the candle-power of the projected beam measured along the axis when the lens is used

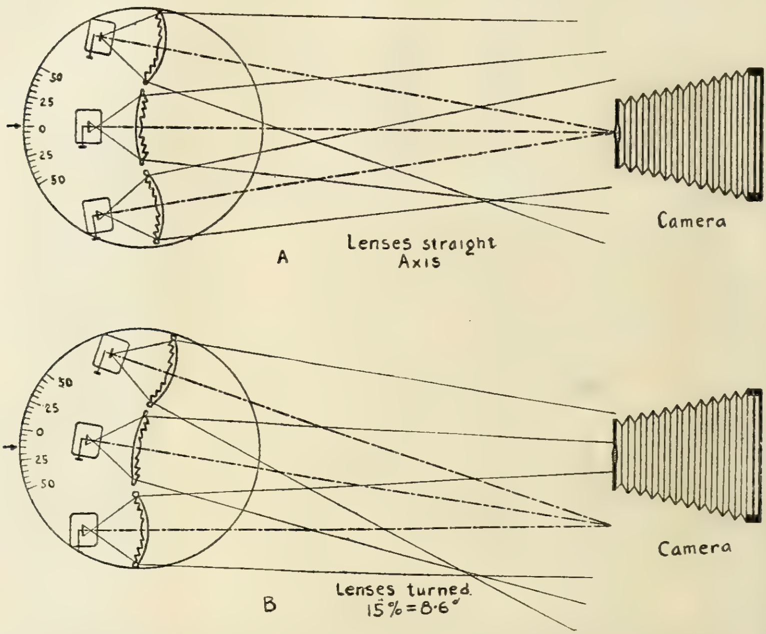
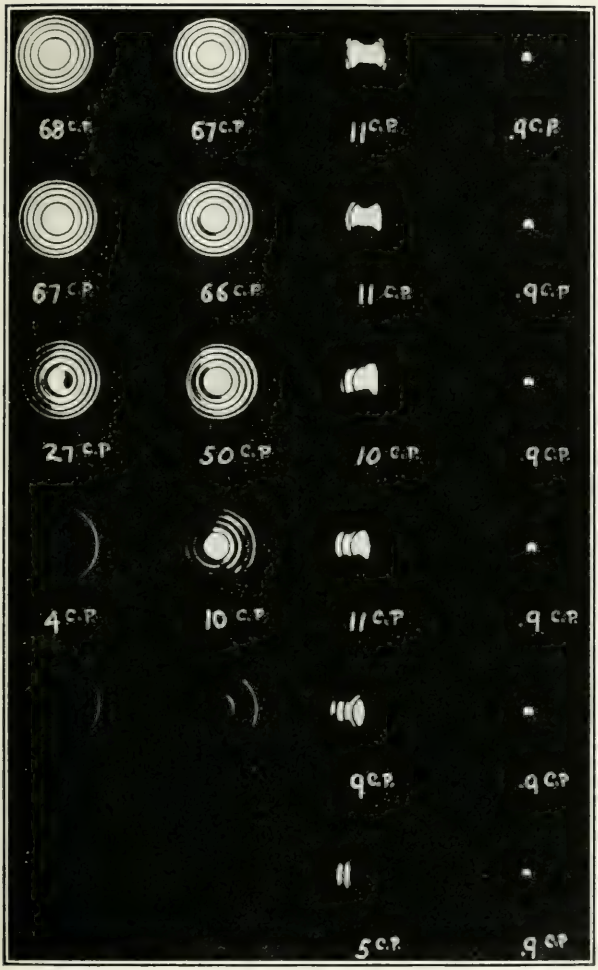


Fig. 11.—Three lenses set up to photograph appearance when viewed directly. A, axis of lenses directed towards objective of camera; B, table top with lenses turned 15 per cent. = 8.6° to one side.

with the long-time burner. Column D is the spread of 50 per cent. intensity measured in feet at a distance of 100 feet from the signal (or measured in meters at a distance of 100 meters from the signal). An angle of 1 per cent. or 1 foot in 100 feet (1 meter in 100 meters) is equal to 0.573 degree. Column E is the extreme spread measured in feet per hundred for the long-time burner. Column F is the candle-power; column



Axis

2.5 % 1.45°

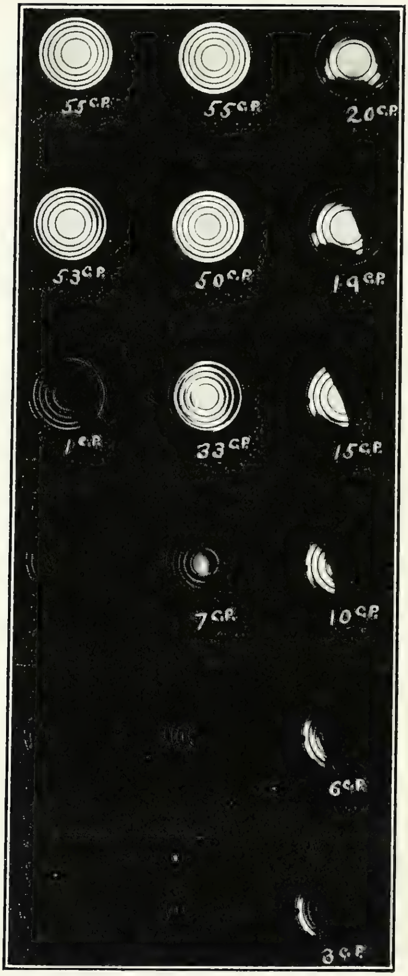
5 % 2.9°

7 % 4°

10 % 5.8°

15 % 8.6

Fig. 12.—Photographs of 5⅜ in. (13.65 cm.) optical, inverted, and wide angle lenses, 3½ in. (8.89 cm.) focus and clear glass roundel with long-time burner, when viewed from different directions with corresponding candle-power measurements marked.



Axis

5 % 2.8°

10.5 % 5.9°

15 % 8.6°

17.5 % 10°

20 % 11.5°

Fig. 13.—Photographs of $5\frac{3}{8}$ in. (13.65 cm.) optical, inverted, and wide angle lenses with one-day burner, when viewed from different directions with corresponding photometric measurements marked.

G is the spread of 50 per cent. intensity and column H is the extreme spread for the one-day burner.

Table II gives the corresponding figures for the inverted lenses.

5. PHOTOMETRIC RESULTS AND PRACTICAL EXPERIENCE.

What is the practical significance of these laboratory results? To have an effective signal requires that the intensity of the projected beam shall have at least a certain minimum value. This minimum value can be determined only by outdoor experiment under conditions approximating those of actual service. Once this minimum is established lenses can be designed to give this value. No matter how well the lens or the signal is designed, it will be effective only when properly aligned, that is, the projected beam must strike the engineer's eye. On a straight track this is a simple matter. A semaphore lamp is usually mounted 25 feet (7.62 m.) above the track and the engineer's eye is about 12 feet (3.7 m.) above the track. Fig. 14 (A). The signal should be picked up at a distance of 2,000 to 3,000 feet, or, in round numbers, 600 to 900 m. This applies not merely to a signal under the best atmospheric conditions, but even to adverse atmospheric conditions, except in dense fog or blinding snow, when no indication will be visible at an adequate range. As the engine approaches the signal, the lower part of the beam is seen until, at close range, the indication becomes faint. Accordingly in adjusting the lamp the upper part of the beam should be projected parallel to the track and the lower part thus be visible as the signal is approached. The upper part of the beam comes from the lower part of the flame, and if the flame should diminish in height and brightness, it will be the lower part of the beam, seen on near approach, which will suffer.

On curves, the problem is more difficult. The brightest part of the beam must be directed towards that part of the track at which it is most important that the signal be seen; this is evidently not along the tangent to the track but at some point on the curve 1,500 to 3,000 feet, or, in round numbers, 450 to 900 m., away from the signal, Fig. 14 (B). As the signal is approached, its intensity must not appear to diminish, but it must appear to

increase, otherwise it will not create as strong an impression on the engineer's mind as it should. It is suggested that in order to get the best results, not the axis, but one side of the beam should be directed along the tangent to the track, also that an

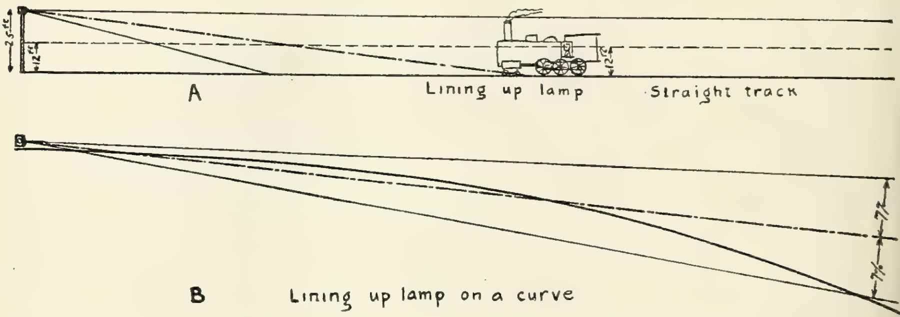


Fig. 14.—Alignment of semaphore lamp. A, alignment for straight track, vertical section; B, alignment for curve, horizontal section.

inverted lens should be used, or in case of an especially crooked track, where great intensity is not so much required as is great spread, that the spredlite lens be used.

It is hoped that photometric data such as given above may be of assistance to the signal engineer in choosing the type of lens to be used for a given set of conditions, and, in determining the correct alignment of lamps, to give the best results as signal indications.

DISCUSSION.

Dr. Hunter H. Turner (Communicated): This paper shows a great deal of thought and careful, painstaking preparation, and is to me quite interesting and instructive.

However, there is one point to which, as an ophthalmologist, I desire to direct attention. Dr. Gage says that "to have an effective signal requires that the intensity of the projected beam should have at least a certain minimum value." While a standardized signal light, of a certain minimum value, may be very desirable from the viewpoint of economics, yet, from the viewpoint of utility in actual service, we fail of our desired goal and jeopardize traffic, in the absence of thorough standardization of

retinal sensitiveness to light impressions and the quickness of mental perception of visual images on the part of engineers, firemen and other employees. These functions, in several individuals, each of whom may have so-called normal vision, may vary within quite wide limits and even in the same individual at different periods, depending upon physical and mental fatigue and upon habits of living. A light of fixed intensity, which is easily and quickly discernible at a given distance to one individual may, at another time, under exactly similar circumstances be hardly perceptible to the same individual or to another, yet in both instances the eyes may be perfectly normal.

Therefore, to make signal lights of standardized minimum intensity truly practicable, would involve the thorough standardization of the functions mentioned in railroad employees, which the varying retinal sensitiveness, even in the same individual, at different times and under varying physical conditions, renders very uncertain. Otherwise, safety requires that the intensity be well above the minimum in order that the signal may be clearly visible to all grades of retinal sensitiveness (short of disease) and be as effective as possible under adverse weather conditions and at the greatest possible distance.

Mr. C. K. Freeman (Communicated): Fig. 14 is of particular interest as it indicates the popular trend of mind to project a luminous indication from a signal lamp with large horizontal angle to cover curved portions of track. This desire on the part of railway officers dates back some twenty years, to the writer's personal knowledge. Inquiry of locomotive runners has repeatedly brought forth the fact that they would like to see signals as far around a curve as possible.

The photographs in Figs. 12 and 13 showing lenses illuminated by long-time and the one-day burners, when viewed from different angles, is most comprehensive and would indicate the desirability for better alignment of signal lamps and that lenses of greater horizontal spread will correct many of the present ills.

DISCUSSION OF A SIMPLE UNIT METHOD FOR MEASURING THE ACTINIC EFFECT OF ILLUMINANTS, BOTH PRIMARY AND SECONDARY, IN THE PRACTISE OF PHOTOGRAPHY.*

Mr. F. N. Steadman (Communicated in reply): Dr. Nutting's first point is very well taken, *i. e.,* I have failed to give references to the works of other writers on these same subjects. It was nearly fifteen years ago and in Mexico that I developed my own theories on exposure. The truths seemed to me to be self-evident. A brighter surface to photograph, a larger stop in the lens, and a faster emulsion, all called for a shortening of exposure and vice versa. These basic principles seemed to me so easy to comprehend that I took no trouble to ascertain who had written about them before me and did not realize that there could be two opinions about them. My wonder was that the values involved had not been expressed in simple numbers. This was due to the fact that I had never been in touch with the educational side of photography, but developed my ideas at first with the sole thought of dominating certain difficult problems which presented themselves in my daily practise. I needed every day a sure method of exposing under the varied conditions of light which I found in private homes from morning till night, in and out of doors and in different kinds of weather.

At this point I wish to go on record as a matter of history that I developed at that time a complete system of exposure based on the measurement of the light by taking the least visible tint on a small strip of solio paper, without being aware that such methods had previously been used by others. This method was first published in a restricted form (adapted to a certain film and certain cameras) by the Eastman Kodak Co in 1904 and the complete method was published about three years ago.

The idea of a unit of convergence or "solid angle" was thought of and sought some fifteen years ago. I had arrived at making quite uniformly good front view lightings by ordinary windows but the changeable elements were many. There were the width

* For paper bearing this title see p. 265, No. 3, vol. IX, Trans., I. E. S.

of the window, the thickness of the wall of the house, as in frame and brick or stone houses, the condition of the light outside, or the actinicity of the portion of sky that lighted the head. The latter condition was varied not only by the season of the year and the hour of the day but by irregular weather as well. Also there was left the variable element of complexion in the subject. I conceived the idea of placing the subject in a position relative to the window that would preserve always a certain geometrical form of light cone to illuminate the head. I closed the window with a dark cloth from the height of the subject's head down and conceived the remaining practically square opening of the window to be one of the uppermost quarters of one side of a cube and placed the head where the center of the cube would be; that is, the head was placed within the room away from the *outside* of one of the window casings at a distance equal to the width of the window. Such an opening admitted light from one twelfth of the whole sky as may easily be understood, and the form of the light beam was constant regardless of the width of the window and the thickness of the wall. This act gave birth in my mind to the idea of the rationality of the convergent theory of calculating light action and after several years of thought and failure, to the idea of a unit of solid angle in the form of a cone.

Soon after devising the above fixed beam of light from windows I conceived the idea of dominating the changeable element of light intensity by the use of solio paper brought to a "least visible tint." The unit method as I have it now was not perfected until some four years ago. All these years were full of hard work from morning till late at night and I may easily be excused for slighting the reading which would have enlightened me as to the work of others.

I make this rather lengthy explanation because I feel that the lack of references in my occasional articles on photography has subjected me to just criticism. This present summer I expect to read with pleasure and profit many of the books which I should have read years ago.

Dr. Nuttings states further that he does not favor my proposal to adopt a new stop *system* based on F/64 as a unit. I

have italicised the word system. Are we not badly mixed in having to express stop values with a "system"? When we speak of "one man" and "four men" for example, in a problem of labor we use no "system," but simply *state the number* of them involved in the different phases of the problem. I wish that all might see that to do the same with stops, after selecting some convenient small one as a unit, would eliminate all "systems" as well as all confusion as to stop values and the calculation of exposure. If we will simply state values no "systems" will be necessary.

But this thought of a unit of convergence or of solid angle has a bearing on education which is much more important than the mere matter of numbering stops.

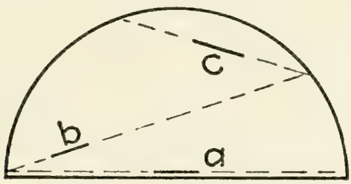
In nature, other things, such as color, texture, smoothness, angle, etc., being equal, the "intrinsic intensity" of any practical point on any surface is caused by the light condition of the whole hemisphere of directions from which the light comes to impinge upon it.

Now the study of light in the books is invariably approached on the basis of a point light source, or a very small one considered as a practical point, sending its rays outward in all directions onto a surface of a certain area and at a certain distance, such surface being concentric to the point light source. The law of "inverse squares" plays a great part in the calculation of intensities. Also the scientists very truthfully state that the law of inverse squares is never true except with light spreading from a point. Now it is a truth each day better understood that a wide area of light source having a comparatively low value, as in indirect illumination, is an approach to nature's way of lighting.

Should a light source be uniform in value throughout and so expanded as to occupy a complete hemisphere of space about the surface illuminated, it is plain to be seen that distance as a factor of calculation and also the law of inverse squares is *completely annihilated.* Under the above conditions the actual size of the hemisphere would be negligible. Neither would the position of the lighted surface matter so long as its plane was wholly confronted by the lighted area. The intensity would be

the same on the lighted surface whether at *a, b,* or *c* in the accompanying figure.

Now such a dome of light source is practically a duplicate of our sky expanse when the sun is not present and it is certainly evident that neither by the element of distance nor the law of inverse squares can we explain this condition or calculate its variations. But when we measure such a condition on the basis of convergence or solid angle we are using a measure which has the the "same nature as the thing measured." In doing this we are in accordance with the requirements of science. Were we to darken in any manner one half of the hemispherical dome of light we would decrease to one half the intensity of the lighted surface, supposing it to be at the position *a*.



Nature's way of lighting, as I have already suggested, agrees frequently and quite perfectly with the hemispherical source illustrated. A room with well distributed indirect illumination over both ceiling and walls (a scheme not recommended, of course, in practise) is like the sky when the sun is below the horizon or when it is hidden by a small, dense cloud or when the weather is hazy or cloudy enough to completely hide the sun and uniformly cover the whole sky. Also any open conditions in the shade as on the shady side of a house present a very like problem.

It is in the field of education then, to establish a way of thinking that agrees with the workings of light in nature, that the convergent method of light calculation is needed. The unit expression of surface actinicity and the numbering of lens stops with their unit value are but the rational applications of the system.

In very few words I will reply to some other points of Dr. Nutting's discussion. He thinks that my definition of speed will

add still greater confusion to the present confusion in photography. Now to express speed in units of time is certainly simple. Under unit conditions of stop and subject actinicity some slow plates and films require eight minutes to properly expose, other faster ones will expose in four minutes and still others are fast enough to expose in two minutes. I hope that I am not deceiving myself in thinking that this method is simple. It is true, however, that this simplicity can be reached only through the employment of unit measurements in stops and actinicity.

Again Dr. Nutting says: "Mr. Steadman's objection that lens stops are not necessarily numbered at their true value is well taken." I cannot find any reference to this matter in my paper. I did say that thousands of cameras were turned out each year without any stop numbering whatsoever. If this is what he refers to it may be pointed out I have already explained that these are the Brownie class of cameras which are given generally three stops, but in the smaller sized cameras only one, which stops are without any numbers or any indication of either their real or relative values.

While the matter is irrelevant to my paper, still it is interesting to note Dr. Nutting's statement that lenses sold under a marked speed of F/4.5 are really F/4.7. I was unaware of this custom in marking speeds. The error involved is 9 per cent. Should a maker of quart cups or of any other measure that is looked after by the Bureau of Standards err in the same degree there certainly would be a scandal.

Further, as to Dr. Nutting's reference to the relation between the brightness of the object and that of the image, I will say that I did not mention it, as with any lens markings it would have to be accounted for. It has no bearing on the numbering of stops, but is purely a problem in the use of them. Needless to say that my method takes this matter into consideration and provides a very simple solution and working guide for the photographer.

In closing this discussion I must compare the rule of exposure which Dr. Nutting says is "now in general use," with my own,

since he believes that my method "adds greatly to the chaos of photographic practise" which I deplore.

The rule which he gives is as follows: "Multiply together plate *inertia* (H & D), *aperture* ratio squared of lens stop and *luminosity* of low lights of object and divide into a constant." For "aperture ratio squared" I offer the working dimension of the stops expressed in unit terms or their unit solid angle Instead of "luminosity of low lights of object" I offer the actinicity of the subject's high lights expressed in unit terms. (The high lights of a subject become the upper or dominant part of the scale of tones in the resulting photograph and are therefore the most important to consider. My method covers, of course, the analysis of contrast in subjects and the ways for securing it and the proper rendition of tone scale and detail throughout the range of the plate's capacity.) For the "plate inertia" (H & D) I offer the "speed" of the plate expressed in minutes. This speed, as I have already stated, is the exposure to give to secure a perfect negative when the unit stop is used in the lens and the actinicity of the high lights of the subject is one unit or one "actino." My rule resolves itself then into the following: Divide the unit exposure time of the plate used by the unit actinicity of the high lights of the subject to ascertain the exposure to give with the unit stop. Divide the exposure for the unit stop with the unit value of any stop used to find the exposure with that stop.

This method *analyzes* the problem. Nothing appears except the actual values and dimensions involved and the reasoning is such that it can be done by persons who have no special education whatsoever, as I have already tried to make clear.

In view of Dr. Nutting's statement that the rule which he quotes is in "general use" I must again recall the facts of the extremely high percentage of camera workers who *guess* at exposure and of the great percentage of cameras in use which have no numbers on the lens stops.

The statement that the theories of Hurter and Driffield are "generally accepted" applies in my opinion almost wholly to students who interest themselves in the study of photography. It is an undeniable fact, however, and one which Dr. Nutting

himself acknowledges, that the condition of photographic *practise* throughout the world is in an inexcusably deplorable state. It is this condition that I am striving to improve with a unit method of measurement and calculation. I offer for the most part simply a new way of thinking about principles which are already well understood by those who have had the interest to investigate them. It is a simple request to ask that simple dimensions and values be expressed in unit terms so that they may be used by people who have no special education.

I am glad to recognize that the principles of photography were well understood by different writers long before I devoted myself to the development of a unit system. That my theories of the principles, although developed independently, agree with those of other writers, as Dr. Nutting says, helps to prove the simplicity of those principles. What I deem very important for the cause of photography and education in general is that we assemble these principles in a unit system so that the study of them may belong by its nature in the common school arithmetic.

I wish to thank Dr. Nutting for his discussion and I hope that the importance of the subject involved will excuse my fault of taking advantage in replying to argue further and at some length for the rationality of my unit method.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 4, 1914

PART II

Miscellaneous Notes

1914 Convention—Cleveland.

The eighth annual convention of the lluminating Engineering Society will e held in Cleveland, September 21 to 5. Plans under way promise a meet- ig which will eclipse the record of any revious meeting of the Society in the ay of number and standard of papers, nd attendance. Mr. W. M. Skiff of ie National Electric Lamp Association, leveland, O., is chairman of the Con- ention Committee. The program of apers and announcements pertaining to ie convention will appear in the next sue of the TRANSACTIONS which will e published about September 1.

Council Notes.

The last regular council meeting in the resent administration was held in the eneral offices of the Society, 29 West 9th Street, New York, N. Y. Those resent were: C. O. Bond, president; oseph D. Israel, general secretary; . B. Marks, treasurer; Preston S. lillar, C. J. Russell, and G. H. Stickney. r. A. S. McAllister, president-elect or 1914-1915, was also present upon ivitation.

Upon recommendation of the Finance ommittee the payment of vouchers o. 1732 to No. 1761 inclusive aggre- ating $1,150.64 was authorized.

The Finance Committee recommended iat the president urge the Sustaining lembership Committee to make a ecial endeavor to increase the number f sustaining members before August 1.

Four resignations were accepted, sub- ct to informal reinstatement, should ly of the members be induced to con- nue their memberships.

The memberships of thirteen members were cancelled in default of payment of dues and fees.

The Committee of Tellers presented a report giving the results of the recent annual election. The names of Society and section officers for the coming year will be announced in the next issue of the TRANSACTIONS.

A progress report of the Papers Committee was read by Mr. G. H. Stickney, chairman.

A written report of progress was received from the Committee on Education, Mr. Preston S. Millar, chairman. The report stated that (1) the Committee is undertaking to ascertain what is being done in the way of laboratory work in illuminating engineering, or in other courses applicable to illuminating engineering, in 123 schools and colleges; it included (2) a tentative outline of a four-year course in instruction which might lead to the degree of illuminating engineering and a one-year post-graduate course; (3) an analysis of literature (text books) on illuminating engineering.

The following committee appointments were confirmed:

1914 Convention Committee: S. G. Hibben; C. L. Eshleman, chairman, Attendance Committee; F. R. Hutchinson, chairman, Publicity Committee; Dr. E. P. Hyde, chairman, Reception Committee; C. T. McKinstry, chairman, Entertainment Committee; H. N. Sibbald, chairman of Transportation; A. G. Summerell, chairman, Hotel Committee.

It was voted that the annual meeting of the Society be postponed from the second Friday in June to a date in the month of October to be announced later. The Executive Committee was authorized to straighten out the disagreement between the annual meeting date given in I. E. S. Constitution and

that in the corporation charter of the Society.

The Council authorized the general secretary to prepare a report of the Council to be submitted at the annual meeting of the Society.

Written reports on section activities were received from Messrs. J. W. Cowles, vice-president of the New England Section; W. J. Serrill, vice-president of the Philadelphia Section; and G. H. Stickney, vice-president of the New York Section.

Section Activities.

Pittsburgh was the only section which held a meeting in June. The meeting was held at the Hotel Schenley, June 19. Dr. J. A. Brashear gave a talk with lantern slides entitled "An Evening with the Stars." The retiring chairman and secretary gave brief summaries of the work of the section during the past year. The meeting was preceded by an informal dinner. Thirty-eight members and guests were in attendance.

New Members.

The following applicants were elected members of the Society at a meeting of the Council held June 11, 1914.

BROOM, BENJAMIN A.
Mechanical Engineer, Wm. L. Steele, Architect, 400 United Bank Building, Sioux City, Ia.

BURGESS, A. E. C.
Consulting Engineer, A. C. F. Webb & Burgess, Culwulla Chambers, Sydney, Australia.

DUNMIRE, R. P.
Illuminating Engineer, Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa.

HAYNES, PIERRE E.
Chief Gas Tester, City of Chicago, Room 614, City Hall, Chicago, Ill.

MONVILLE, FRANCIS X.
Superintendent of Building, The Philadelphia Electric Company, 1000 Chestnut Street, Philadelphia, Pa.

STEVICK, C. H.
Superintendent, New Amsterdam Gas Company, Ravenswood, Long Island City, N. Y.

New Sustaining Member.

The United Gas Improvement Company, Broad and Arch Streets, Philadelphia, Pa., was elected a sustaining member at a meeting of the Council held June 11, 1914.

Notice of Special Meeting.

To the Members of the Illuminating Engineering Society:

Notice is hereby given that a special meeting of the members of the Illuminating Engineering Society will be held in the general offices of the Society, 29 West 39th Street, New York, N. Y., on the 3rd day of September, 1914, at 2.00 o'clock P. M., to act upon a proposition to alter its certificate of incorporation so as to change, first, the time of the annual meeting from the second Friday of January in each and every year, to a convenient date in October, in each and every year, which meeting may be adjourned from time to time; and, second, the present item of the charter reading "That the number of directors of said corporation shall be seventeen (17)," so as to read *The number of directors, that is the total number of members of the directing Council of*

Society, shall not be less than seven-n (17).

Dated, New York, N. Y.,
July 23, 1914.

JOSEPH D. ISRAEL,
General Secretary.

The first change is required because present annual meeting date is in-venient; the second change so that actual number of directors, which l logically increase with the addition new sections of the Society, may be agreement with the figure given in corporation charter of the Society.

At least nine members must be pres- at the special meeting, which is to held at the above-given time and ce, before the foregoing changes can legally adopted and the charter ered.

Those members who will be unable to end the meeting are asked to kindly out a form proxy like that printed ow and send it so that it will reach ieral offices of the Society, 29 West h Street, New York, not later than ptember 2, 1914.

FORM OF PROXY.

KNOW ALL MEN BY THESE PRESENTS. That I, ..., do hereby constitute and appoint JOSEPH D. ISRAEL to be my lawful attorney, substitute and proxy for me, and in my name to vote at the special meeting of the members of the Illuminating Engineering Society, to be held on the 3rd day of September, 1914, at 29 West 39th Street, New York, N. Y., and at any adjourned meeting thereof, as fully and with the same effect as I might or could do were I personally present at such meeting; and I hereby revoke any proxy or proxies heretofore given by me to any person or persons whatsoever.

IN WITNESS WHEREOF, I have hereunto set my hand and seal this......day of ...., 1914.

....

In presence of....................

Erratum.

Vol. IX, No. 4, page 385: Line 16 should follow line 23.

TRANSACTIONS
OF THE
Illuminating Engineering Society

Published every forty days.
ILLUMINATING ENGINEERING SOCIETY
GENERAL OFFICES: 29 WEST THIRTY-NINTH STREET, NEW YORK

VOL. IX NUMBER 6 1914

REPORT OF THE RESEARCH COMMITTEE.

(*Meeting held May 16, 1914.*)

Present: Messrs. Bond, Langdon, Lancaster, Powell, Amrine, Ferree, Dunlap, Middlekauff, Kingsbury and Ives.

The subject for discussion at this meeting of the Research Committee was:

PHOTOMETRY OF LIGHTS OF DIFFERENT COLORS.

The problem of the photometry of lights of different colors is one of the most difficult in light measurement. It has become of increasing importance during the past few years because of the rapid development of illuminants of wide color range and because all attempts to place photometry on a satisfactory physical basis demand the establishment of the relative light value of different colored radiations. Attention has repeatedly been called to the difficulty of the problem by the widely divergent results obtained by different individuals and laboratories at different times in attempting the photometry of even moderately differently colored lights. When the color differences are large, as between red and green lights, the discrepancies between measurements, even by the same observer, can vary by 100 per cent., depending on the order of measuring the lights and upon whether they are compared with each other or with an auxiliary standard.

Probably the most general statement of the problem is obtained by starting with the definition of luminous flux as *"radiant power,* evaluated according to its capacity to produce the sensation of light." This definition assumes the possibility of ascribing to any quality (wave-length) of radiant energy its relative light

value. The problem of heterochromatic photometry is to arrive at criteria and methods of obtaining this relative light value.

At the outset one meets the question of criterion. While in the case of ordinary photometry (lights of same color) it is easy to agree that the ultimate criterion is what the light enables one to do, and that the accurate methods of photometry are used to record and duplicate the conditions found good, the case is not so simple with colored lights. With the latter different qualities of light have different efficiencies, depending on whether the ability to distinguish detail, to appreciate the presence of light or to detect movement, be taken as the measure. There are for this reason several different answers to the question: What relative value shall be given to the colored lights A and B? This complexity of the problem is inherent and can be simplified only by the adoption of certain partly arbitrary conventions. For instance, if it be found that one criterion is by far the most important this may be worked to and data may be obtained which will make easy the correction to other less used but occasionally required criteria.

Apart from the choice of criterion there are several striking factors of difficulty in this sort of comparison. First of all one has to face the fundamental difficulty that the eye can equate, but cannot appraise, and it can equate only if the two brightnesses under comparison are identical in quality. If a color difference exists a true condition of equality cannot be found. Brightness cannot be separated from color. In comparing two adjacent fields of different color a decision must be reached as to what to call equality of brightness. This judgment is apt to differ between different individuals and in the same individual at different times.

The next difficulty to be met with is that the relative light values of different colored radiations change with the absolute brightness and with the angular extent of the surface viewed. These changes are different in magnitude and even in direction with different photometric methods.

A third difficulty is that caused by or accompanying differences of color vision of different individuals. These differences are quite distinct from differences in judgment. Individuals having pronounced color blindness in any of the typical forms are apt

to obtain anomalous results in colored light photometry, but similar deviations from normal, although of less extent, are to be found in any group of observers. No matter what method of photometry is used, it will be necessary to obtain the average results of numerous observers in establishing standards. Conversely any average value will be in error for any individual.

The committee discussed the various methods which have been used to compare lights of different colors, considering them from the standpoint of sensibility and reproducibility and in connection with the disturbing factors just reviewed.

In regard to questions of sensibility, an important distinction should be given attention in this matter, namely, that between precision and accuracy. It is not sufficient for a method of colored light photometry to give precision. High sensibility and reproducibility of results are of no value unless the results be right. Thus a photo-electric cell may give perfectly definite and reproducible values for an illumination, but it is measuring radiant power evaluated according to its capacity to produce the photo-electric current, and not the sensation of light.

The chief distinct methods of colored light photometry are equality of brightness, visual acuity, persistence of vision or critical frequency of disappearance of flicker and the flicker photometer.

The equality of brightness method labors under the disadvantage of low precision.

Visual acuity has low precision and measures not brightness alone, but quality, because monochromatic light is rated higher by it than complex light.

The critical frequency method has low precision.

The flicker photometer, where the two compared brightnesses are alternated, has high precision.

All methods are affected to greater or less extent by the changes in illumination, field size and differences in the vision of observers above noted. Quantitative evaluation of the extent of these effects over very wide range is to be desired. Certain experimental work has indicated that the Purkinje and allied effects are of continually decreasing magnitude as higher brightnesses are attained.

In view of the greater precision of the flicker photometer it offers great advantages. Question has been raised as to whether it measures true brightness. Experimental results indicate that at high illuminations the values obtained with the flicker photometer approach more and more closely the results of the mean of measurements by equality of brightness and to the results obtained by the cascade or small step method. What is most needed at the present time is a satisfactory explanation of the action of the flicker photometer.

During the meeting two theories brought forward by members of the committee were discussed. One is based on the experimental data showing that the different color sensations rise to their final values at different rates. On this theory the flicker photometer cannot measure true brightness. The other theory assumes the fluctuating stimulus to be transmitted by a medium of varying conductivity for different illuminations and colors. As a consequence the amplitude of the vibration is reduced. The sensation of two dovetailed vibrations gives no flicker if the amplitudes are equal. From this theory it follows that the flicker photometer measures a condition which at low illumination approximates the critical frequency values, at high illuminations the equality of brightness. Work in connection with these theories is in progress and will be published shortly.

Physical photometers available for colored light photometry were next discussed. In addition to the qualities of precision sensibility, simple stimulus-response relationship and convenience, discussed at the previous meeting, the additional one is now added that the wave-length sensibility must be that of the normal eye under stated or standardized conditions. Should such a physical photometer be developed it should make possible the elimination to a large extent of visual colored light photometry with its attendant difficulties.

The meeting closed with a brief discussion of practical devices to eliminate color differences in practise. Color screens and auxiliary standard lamps of different colors fall under this head. Using these it is possible to make practical photometry always that of lights of the same color, so that differences between individuals and most errors of estimation are avoided. All of these

schemes, however, demand an original approved method of calibration; this, however, they place with the standardization laboratory.

A partial bibliography of the subject is appended. The correspondence between the various members of the committee and the chairman, containing in greater detail the material of which this report is a summary, will also be on file and may be consulted by interested parties.

HERBERT E. IVES,
Chairman.

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REPORT OF THE COMMITTEE ON PROGRESS.

To the Illuminating Engineering Society:

Since the last report on progress the developments in the science of illumination and in the lighting industry have continued to an extent which proves that there has been no lessening of public interest and no cessation in the demand for improved lighting conditions.

The "Safety First" slogan is reflected in the fulfilment of the requirements for safety lamps in mines. The detrimental effects of glare have been recognized and an effort has been made to avoid them in the headlights of automobiles. The very considerable increase in the intensities available in both gas and electric sources has made possible to a much greater extent than ever the use of diffusing globes and shades and stimulated the demand for artistic fixtures.

The recognition of the scientific side of illumination has been growing and there seems to be more and more of a tendency on the part of those who control the lighting of buildings, stores, etc., both owners and architects to take into account the principles which have been so faithfully promulgated by this society.

In general the same plan has been followed as that inaugurated in last year's report. The custom of adding references has been continued in order that anyone interested in any special detail may know where to look for further information. It is hoped that no one will impugn the impartiality of this report the sole purpose of which has been to present without prejudice the more important advances in the subjects dealt with under the various headings.

The committee desire to express their appreciation of and acknowledge with thanks the data so courteously given by the engineers in charge of lighting in the various cities and by the

* A report read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

representatives of various manufacturing concerns who have cheerfully responded to requests for information.

Respectfully submitted,

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E. L. ELLIOTT,
H. S. HOWER,
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SUBJECTS.

GAS LAMPS AND APPURTENANCES.

Burners.—What is claimed to be one of the most important developments since the introduction of the incandescent gas mantle, lies in a new type of burner.[1] Application is made of a recently discovered principle of gas lamp design, and the result is a lamp in which the operating costs are practically cut in two. The necessity for the use of cylinders is avoided. The new burner works on a novel principle in that the kinetic energy of the gas is fully utilized to secure uniformity of mixture, which is accomplished by providing scientifically designed stream lines for the gases.

For residential work very small mantles are used, giving ap-

[1] *Amer. Gas Lt. Jour.*, April 3, 1914, p. 77.

proximately 30 candle-power each, which are considerably stronger than the older types. These small mantles are used in clusters of three, so that in case of accident to one, illumination is not completely shut off.

Another innovation in burners utilizes experimental data[2] indicating that in the bunsen burner of either the upright mecker type or the ordinary inverted form, the highest temperature is immediately above the points of the small green inner cones. This discovery has led to the construction of an inverted mantle burner in which the mouth of the tube is covered with a fine wire net which forms the desired green cones. The mantle lies immediately below these cones. The permanent gas consumption of the lamp is given as 0.69 litre per candle-power a factor which approaches results obtained with high pressure gas.

Use of the regenerative principle is made in a new burner[3] for either high or low pressure gas. The secondary air is passed through a heating chamber, heated directly by the products of combustion, and is delivered to the lower surface of the mantle. Efficiencies as high as 50 candles per cu. ft. (0.28 cu. m.) of gas (mean lower rating) have been obtained with burners using this principle.

The high pressure lamp using fused silica for the globe or cup has been still further developed.[4] The increased temperature of the burner nozzle owing to the proximity of the cup and consequent concentration of heat, required a search for suitable material which has recently been found. The tendency to explode the contents of heater and mixing tube on turning off the gas has been remedied by enriching the mixture beyond the explosive range at the moment of extinction. Improvements have been made also in the design of the lamp as a whole both from the utilitarian and aesthetic standpoints.

A new method which claims to increase the life and light giving power of gas mantles[5] consists in dipping the new mantle into a solution of kaolin and permanganate of potash. It is then thoroughly dried at a moderate temperature and may be burned

[2] *Jour. f. Gas.*, March 7, 1914, p. 217.
[3] *Amer. Gas Lt. Jour.*, May 4, 1914, p. 286.
[4] *Jour. Gas Lt.*, April 28, 1914, p. 233.
[5] *Jour. Gas Lt.*, March 17, 1914, p. 723.

off and used immediately or laid away. In order to preserve the mantle it is recommended that the immersion be repeated, two immersions sufficing to increase the life and usefulness much beyond the average.

An elaborate investigation has been carried out on the influence of the form of the mixing tube, on the injector action, and heating effect on the tube, in a mantle burner.[6] One of the results reached is that for the ordinary low pressure burner which takes in the primary air of its immediate surroundings without suction, the best operating conditions are obtained if the air openings taken collectively are kept at least three times the area of the cross section of the lower mixing tube opening.

A complete explanation has been worked out for the fact that a conical enlargement of the mixing tube remedies the objectionable heating (objectionable from the standpoint of thermo-dynamics) in the case of those burners whose air-gas mixture becomes heated on its way to the mouth of the burner. Furthermore it has been shown that a mixing tube made up of a series of cylindrical pieces of progressively increasing diameter is completely equivalent to a conically diverging tube.

Automatic Lighters.—The question of the automatic gas lighter continues to interest the inventor and during the year a number of new devices have been described. Among these may be mentioned a pyrophoric distance gas lighter[7] which causes a cerium-iron block to be rasped by a file in the form of circle controlled, through a toothed wheel and rack, by a solenoid. The current through the solenoid is governed by a button or other suitable device. An electric type has a by-pass and a heated platinum wire. Another pyrophoric device is arranged on the chain pull system.[8]

Abroad automatic ignition has found considerable favor, but until recently it has not gained much headway in this country.[9] However two systems are being introduced which look promising and have already met with some success. One uses a valve operated by a change in pressure in the line leading to the lamp

[6] *Jour. f. Gas.*, November, 1914, pp. 1069, 1097, 1125.
[7] *Elek. Anz.*, January 15, 1914, p. 67.
[8] *Jour. Gas Lt.*, February 3, 1914, p. 295.
[9] *Proc. Amer. Gas Inst.*, November 8, 1913, p. 349.

while in the other a small auxiliary gas line is used to operate the valve.

A foreign system of electric ignition has been developed in which electricity at low pressure is carried from the point of control to the fixture, where by means of a miniature induction coil it is stepped up to the sparking point. An improvement on this device, worked out in this country, utilizes the low voltage supply to operate the valve and the high voltage to produce the spark, the whole apparatus being confined to a single small receptacle which can be placed in the canopy of the fixture.

Tubing.—A most important auxiliary[10] of the portable gas lamp is the connecting tubing, generally of rubber. As the result of experiments with lime, glycerine, and powders, a new tube has been developed which is claimed to be quite impermeable to gases and will last several years without serious depreciation. The heat resistance is good, its pressure resisting capacity greater than that of rubber and its cost is low.

Carbureted Air.—Where coal is dear and petroleum or gasoline is abundant,[11] the use of carbureted air for village lighting has seemed highly desirable owing to the inexpensive character of the plant required. But technical difficulties have hitherto stood in the way of the general adoption of this system. A new procedure[12] eliminates many of the former difficulties by carbureting the air in the immediate proximity of the burner where it is to be used instead of doing so at the works. The main distribution system then becomes one of compressed air, while the carburetors are located at stations situated at different parts of the area of supply.

It is claimed that Balcombe, a Sussex village, is the first English village to have its own petrol air gas supply, the latter having been recently installed.[13]

Acetylene.—An Italian society, The Société Générale, has offered a prize of 500 lira for the best type of acetylene lamp for use on bicycles.[14]

Two years ago there were 106 government acetylene naviga-

[10] *Jour. Gas Lt.*, March 3, 1914, p. 565.
[11] *Light Jour. & Eng.*, (London), May, 1914, p. 243.
[12] *Jour. Gas Lt.*, April 21, 1914, p. 188.
[13] *Light Jour. & Eng.*, (London), June, 1914, p. 248.
[14] *Sci. et Art le l'Eclair*, January, 1914, p. 1.

tion lights in use exclusive of buoys.[15] The last report shows an increase of 246 and a proposed further increase of 43.

The developments in the use of acetylene in mines will be mentioned under another heading.

Kerosene Incandescent Lamp.—A successful wick feed kerosene incandescent lamp has been perfected and is being introduced for rural lighting in this country.

ELECTRIC INCANDESCENT LAMPS.

Non-Vacuum High Efficiency Tungsten Lamps.—Last year's report contains a brief statement heralding the advent of the high efficiency tungsten lamp, and its introduction in a wide variety of sizes constitutes the most marked development in the sphere of the electric incandescent light. The use of the spirally wound filament in an atmosphere of neutral gas has made possible a higher temperature and a consequent considerable increase in light intensity, while at the same time bringing the source itself into such a relatively small space as to enhance its value when used in searchlights, in projection lanterns or with focussing reflectors.

At the time of the 1914 report of the Lamp Committee of the National Electric Light Association[16] these lamps were available in the following sizes: for multiple burning on 100-130-volt-circuits 400, 500, 750 and 1,000 watts or in candle-power 535, 715, 1,250, 1,820; for series burning the number of units was larger ranging by moderate steps from 60 to 1,000 candle-power with a voltage range from approximately 6 to 55 and in amperes of 5.5, 6.6, 7.5 and 20. In England for the 100-130-volt range, lamps were announced of 400, 600, 1,000, 1,500, 2,000 and 3,000 mean hemispherical candle-power.[17] At the same time announcement was made of series burning 50-65-volt lamps in 200, 400, 600 and 1,000 candle-power sizes, and of multiple burning on 200-260-volt circuits in 1,000, 1,500, 2,000 and 3,000 candle-power sizes. Subsequently this listing has been extended considerably.[18] In this connection it should be noted that the changes in schedules of these new lamps have followed each

[15] *Acet. Jour.*, March, 1914, p. 346.

[16] Report of Lamp Committee, National Electric Light Assn., June, 1914.

[17] *Elec. Eng.*, (London), February 19, 1914, p. 108.

[18] *Elec. Eng.*, (London), July 23, 1914, p. 422.

other with such rapidity that before this report is published there will doubtless be available new limits of voltage and efficiency and new ranges of candle-power and watts.

In Germany the 50-volt, 110-volt and 220-volt types were advertised late in the fall.[19] These lamps were tipless and contained nitrogen at an absolute pressure of about nine pounds per square inch (0.53 kg. per sq. cm.).

The new high efficiency lamp is being used in German theatres,[20] and in this country in many places requiring very intense sources, such as display lighting and for the lighting of large areas. It is already a strong competitor of the ordinary arc lamps and the high power gas arcs. Efforts are being made[21] to develop this lamp for use in moving picture machines where steadiness and high intensity are important.

Investigations of the properties of this new lamp have indicated[22] a reduction factor in the neighborhood of 0.850, a temperature of approximately 2,600° C. and a ratio of radiated energy to energy input of 60 per cent. as compared to 88 per cent. for the ordinary vacuum type tungsten lamp. A study of the energy distribution showed the wave length of maximum energy to lie close to 1.1 μ ($\mu = 0.001$ mm.) and the ratio of luminous to total energy radiated to be approximately 8 per cent. as compared to 4 per cent. for the ordinary vacuum lamp. The ratio of energy radiated in the visible part of the spectrum to the energy input was found to be approximately 5 per cent. as compared with 3.5 per cent.

Vaccuum Tungsten Lamps.—Since the first of the year there has been a 10 per cent. increase in efficiency in the ordinary drawn-wire tungsten lamp[23] both in the multiple type and also in the street railway and train lighting lamps and this has been accompanied by a decrease in price of from 10 per cent. to 15 per cent.[24] There seems to be a steadily increasing tendency on

[19] *Elek. Anz.*, October 9, 1914, p. 1144.

[20] *Zeit f. Bel.*, June 10, 1914, p. 200.

[21] *Elec. World.*, March 28, 1914, p. 713.

[22] *Zeit. f. Bel.*, January 20, 1914, p. 14; *Zeit. f. Bel.*, March 10, 1914, p. 75; *l'Electricien.*, June 6, 1914, p. 353.

[23] *Cent. Sta.*, March 1914, p. 354.

[24] *Elec. World.*, March 28, 1914, p. 684.

the part of central stations[25] to further the use of the tungsten lamp through free renewals and decreases in prices.

According to the Lamp Committee report[26] the quality of vacuum tungsten lamps has been greatly improved. The filaments have been made stronger; a change has been made from heavy to light semi-flexible or flexible supports; and the introduction of chemicals to prevent blackening has been extended to the lower wattage and been greatly improved in the higher wattage sizes.

A decided improvement in these lamps has been along the lines of standardization and uniformity of the various constituent parts such as bulbs, stems, supports, etc.

Among foreign manufacturers a number of filament mountings have been worked out. One[27] giving a maximum intensity in the lower hemisphere consists of a rectangular glass frame from which the supporting wires hang down, the filament being wound back and forth so as to lie in the same horizontal plane, the lamp being used pendant.

The ability to wind the drawn wire tungsten into spirals of very small diameter has made possible also a variety of methods of mounting.[28] An arrangement giving a result similar to the one just mentioned consists in placing the supporting wires radially in the same horizontal plane and looping the filament between them. Another type[29] uses three vertical glass rod supports with the filament wound spirally around them. Another[30] has the supporting wires in the same plane and forming a four pointed star. In another lamp[31] the filament is wound in the form of an inverted cone, and the bulb is either clear or has its upper half frosted and the lower half ribbed. One type uses the grid form first mentioned with the spirally wound filament. In still another type in order to get a maximum of length[32] in a minimum of space vertically and thereby permit the use of a small

[25] *Cent. Sta.*, May, 1914, p. 417.
[26] *Loc. cit.*
[27] *Zeit. f. Bel.*, October 20, 1913, p. 415.
[28] *Elek. Anz.*, October 5, 1913, p. 1128.
[29] *Elek. Zeit.*. September 25, 1913, p. 1122.
[30] *Elek. Zeit.*, November 27, 1913, p. 1381.
[31] *Elec. Times*, February 5, 1914, p. 152.
[32] *Zeit f. Bel.*, June 20, 1914, p. 221.

diameter bulb, the spiral wound wire is held by supports which carry it spirally around the central glass supports.

This year has seen the almost complete elimination of the tantalum lamp, the number used being less than 0.1 per cent. of the total number of lamps sold, while the number of carbon lamps used has dropped to only 10 per cent.

The government has revised its standard specifications for incandescent lamps.[33] The new schedule calls for 200-260-volt tungsten lamps, raises efficiency limits and lowers voltage limits. The tantalum schedule has been dropped. In both the tungsten and graphitized carbon schedules the sizes of bulbs are named, indicating the progress in standardizing which permits such designations.

An extension of that method of rating lamps for efficiency,[34] based on the fact, that equal efficiency means equal brightness in vacuum incandescent lamps having the same filament material, has been devised. The method is particularly designed for conditions where the testing voltages are fluctuating, and uses either direct or alternating current. The optical pyrometer principle is involved and the apparatus is very simple including a voltmeter and some suitably chosen resistances.

The advent of the high efficiency non-vacuum lamp of high current has necessitated the development of special holders which shall provide ventilation and protection from moisture. In the case of the low-voltage high-current type a compensator for street series lamps has been produced which in some cases effects an appreciable saving in energy.

Various devices have been invented to prevent the unauthorized removal or theft of lamps and reflectors.[35] One of these recently developed is so arranged that a lamp once screwed in cannot be removed without breaking it. Replacement of a lamp is accomplished by breaking the bulb, which allows the slipping off of the outer shell of the socket, and permits the unscrewing of the discarded base.

Difficulties in the manufacturing of carbon lamps in the early

[33] *Bur. of Std.*, Circular No. 13, 1914.
[34] *Light Jour.*, (U. S.), November, 1913, p. 272.
[35] *Elec. Rev. & W. E.*, December 6, 1913, p. 1130.

days[36] are partly responsible for the wide range of voltages in the distributing systems of central stations. But the recent great improvement in the manufacturing processes connected with tungsten lamps has enabled the factory to produce lamps of a given desired voltage to within very narrow limits. It has been suggested that if it were feasible to have central stations adopt a standard voltage, it might be possible to still further reduce the price of lamps by relieving the manufacturer of the necessity of providing for more than one voltage.

Efforts are being made at the present time to have central stations bring their voltage as nearly as possible to the 120-volt center.

ARC LAMPS.

The result of considerable research has brought out an improved electrode for the magnetite arc.[37] This, together with a prismatic refractor which redirects light formerly lost, has made a big advance in the mean hemispherical efficiency of this type of arc lamp.

Improvements have been made also in the flaming carbon arc lights. A new type has been developed in which the lamp forms the top of a pillar and which combines the operating characteristics of the long burning arc with the ornamental design inherent in the adoption of the classic column. Research has shown that good operating results may be secured by the use of a small condenser having vertical, concentric sides.

In response to the demand for ornamental units, the appearance and diffusion of arc lamp globes have received some attention with beneficial results.

In enclosed flaming arc lamps[33] the effects of water in the enclosing globes has been studied recently. It was found that one effect is to lower the temperature of the arc due to the formation of hydrogen which rapidly conducts heat away from the electrodes. It was found also that there is a remarkable shortening in the life of the trim if moisture is present in the globe.

VAPOR AND VACUUM TUBE LAMPS.

Mercury-vapor lamps in general, function on direct current.

[36] *Elec. Rev. & W. E.*, August 1, 1914, p. 202.

[37] *Gen. Elec. Rev.*, March, 1914, p. 292.

[38] *Elec. World*, December 13, 1913, p. 1220.

Those designed for and used on alternating current are arranged so that the final result is a unindirectional action. A new type of quartz mercury arc has been devised[39] having only two electrodes, between which the current alternates. This is made possible at ordinary frequencies (50 volts) by using voltages not less than 600; a pressure not less than of the order of 1 cm. of mercury; the presence of self-induction in the circuit; and when starting having the electrodes already hot. A lamp of this type has been designed for 1,000 volts at the terminals, 1,000 watts consumption, a power factor of 0.7 and a candle-power of approximately 5,000 giving a candles per watt factor of 5.

Another new arrangement of the quartz mercury arc[40] has for its object the production of a light source comparable in intensity with the carbon arc but with the objectionable heating removed. This is accomplished by making the lamp in the form of an inverted U and placing it in a flask one of whose walls is in the form of a paroboloid which may be silvered, and thus concentrate the light emitted through the opposite wall. The flask is made of pure transparent quartz and uses electrodes of invar metal. The whole is then immersed in a vessel either of glass or with glass sides, filled with water. One of the sides may be made in the form of a condensing lens. A lamp so constructed used 18 amperes with 70 volts at the terminals and was claimed to give 3,000 candle-power or about 0.42 w. p. c. Such a source would have its principal application in cinematography or photomicography.

In cases where the tilting method of starting mercury-vapor lamps is not feasible, a new starting arrangement has been devised,[41] which uses a small auxiliary vessel containing a reentrant portion in which a heating coil may be placed without disturbing the vacuum. This small vessel is placed immediately below a part of the tube which is near the negative electrode and constricted. Initially the positive and negative electrodes are connected by a thread of mercury which is broken by a bubble of vapor arising and being caught in the restricted portion when the heating coil is started. The operation may be made quite automatic.

[39] *Bul. Soc. Int. des Elec.*, April, 1914, p. 385.
[40] *C. R.*. November 17, 1913, p. 921.
[41] *Elec. Rev. & W. E.*, October 11, 1913, p. 733.

Neon.—Work is still being done on the study of the properties of the neon lamp.[42] It has been found that, the current being kept constant, the drop in potential along the tube is approximately inversely proportional to the diameter, the tube operating under a pressure of about 2 mm. of mercury and a current density of 6 amperes per square decimeter. The effect upon the luminous power of varying the diameter has also been studied and it has been found that the luminous power increases approximately as the first power of the diameter. Owing to the loss of power at the electrodes, however, tubes of a diameter about 1 to 3 cm. are best if efficiency is to be considered.

In England the neon tube has been put on the market for advertising purposes[43] in a standard length of 6 m. a diameter of 50 mm., and using 1 ampere with 1,000 volts at the electrodes.

Cathode Lamp.—A new vacuum lamp has made its appearance[44] based on the fact that the cathode in a vacuum tube becomes very hot on the passing of a discharge. The inventor utilizes this phenomenon to bring to a glow a piece of Nernst heater used as a cathode and contained in a quartz tube, sealed by means of magnesia and pipe clay into a spherical glass bulb.

The claim is made that with 820 volts and 0.11 ampere, or 90 watts, the lamp burns as brightly as a 50 candle-power lamp. Further study is to be made on this lamp.

Ultra-violet Sources.—For some time quartz mercury-vapor lamps, heavily loaded, have furnished the only intense source of ultra-violet radiation in practise.[45] A method has been recently devised which considerably increases the effectiveness of such lamps by using a magnetic field and water cooling. This has the effect of reducing the density and consequent absorption of the vapor envelope, and shifts to the side of the tube the concentrated beam of light which ordinarily occupies the center of the tube.

Deduced from photographic action the improved lamp shows the greatest intensity in the region $\lambda = 0.254\,\mu$. A further interesting result is that using this lamp to excite a "resonance" mer-

[42] *C. R.*, February 16, 1914, p. 479.
[43] *Elec. Eng.* (London), March 5, 1914, p. 138.
[44] *Elek. Zeit.*, March 5, 1914, p. 259.
[45] *Elec.*, April 3, 1914, p. 1074.

cury-vapor lamp (a quartz glass absorption vessel provided with a drop of mercury, exhausted and sealed) the extremely monochromatic radiation of wave-length $\lambda = 0.2536\,\mu$ may be produced continuously and with considerable intensity.

A study of the oscillating spark between various metal electrodes[46] as a source of ultra-violet radiation has shown a maximum intensity when using invar, the value being almost twice that obtained with copper.

LIGHT SOURCES FOR PROJECTING PURPOSES.

Headlights.—The enormous increase in the use of automobiles both for pleasure and traffic has made the question of proper headlights of steadily increasing importance. In the larger cities particularly legislation to prevent the use of dazzling headlights has been put into effect. One result has been the development of numerous schemes to shut off the excess of light while in the city, but leave the full intensity available for use on unlighted roads.

Instead of using four headlights,[47] two of high power for country touring and two of low power for city driving, one arrangement provides twelve lights placed along the filler board between the wind-shield and the top of the engine hood. When not in use the lamps are completely covered by a sliding shutter which may be moved to permit the use of as many as desired and of particular ones if necessary. Furthermore the angle of the group of lamps can be varied at the will of the driver, so as to illuminate any portion of the road, or the engine of the machine.

In another system,[48] two lamps are used, having a tubular body, fitted with a system of lenses and a reflecting mirror, the result being a concentrated beam projected in nearly parallel rays, and capable of easy direction.

Another form[49] has two pairs of translucent wings mounted on pivots and made to open and close by electromagnets controlled by a push button on the dash.

The National Physical Laboratory has had the subject under

[46] *C. R.*, May 11, 1914, p. 1337.
[47] *Sci. Amer.*, June 20, 1914, p. 497.
[48] *Sci. Amer.*, March 14, 1914, p. 233.
[49] *Sci. Amer.*, March 7, 1914, p. 204.

advisement for some time[50] and recommends the cutting off of the light beams coming from the upper right hand corners. The right hand corner is indicated because in England the rule of the road is to the left.

In regard to locomotive headlights[51] a similar state of interest is evident, but the crying need for definite information as to the actual needs in this direction is evidenced by the fact that in this country twenty-eight states have adopted legislation embodying seventeen different specific laws governing the use of such headlights.

Searchlights.—A big advance in searchlight construction[52] is shown in a new type which has small electrodes, operates at a high current density and temperature and has an improved specific consumption. The current density is about six times that of earlier types of lamps. This is accomplished by forcing alcohol vapor around the electrodes to act as a cooling medium and protect the electrodes from too rapid combustion.

The positive crater appears like a sharply defined point of light of extremely high specific intensity. The feeding of the alcohol vapor takes place automatically when the arc is struck, a valve governed electromagnetically being used for this purpose. Both electrodes are rotated uniformly in order to maintain perfectly uniform bathing of gas, and are placed the one horizontal the other at a certain angle to insure equal combustion.

Signal Lights.—A striking departure from former methods[53] of railway signaling is forecasted in the results of tests made to determine the right intensity of a signal lamp so that it will be clearly visible in bright sunlight and not too dazzling at night. If practical experience proves the system to be as effective as the preliminary tests indicate, the old semaphore arm method of daylight signaling will become obsolete in cases such as electric roads where energy is cheap.

The method of momentarily obtaining high intensity by using a tungsten lamp at voltages much above normal has been utilized in a signaling device for soldiers and airmen.[54] It consists

[50] *Elec.*, July 10, 1914, p. 574.
[51] *Rlwy. Elec. Eng.*, March, 1914, p. 349.
[52] *Elec. World.*, July 25, 1914, p. 181.
[53] *Rlwy. Elec. Eng.*, May, 1914, p. 395.
[54] *Sci. Amer.*, July, 1914. p. 30.

merely of a minute incandescent lamp in conjunction with a parabolic mirror and arranged so that the circuit can be closed intermittently to give long or short flashes, corresponding to the dots and dashes of the Morse code.

Another advance in the use of lamps for signaling is in connection with city traffic. A scheme is being tried out in Cleveland of directing traffic at busy street intersections by red and green lamps placed on cross arms on 15-ft. (4.57 m.) poles at each of the four corners. Control is vested in the traffic policeman who is in a booth at one of the corners.

An improvement on the reflecting portion of the light source of light-houses[55] uses a mirror composed of elements both parabolic and annular combined with a spherical mirror. The former project the rays emitted from the front of the lamp, and the latter those from the rear.

MINER'S LAMPS.

The past year has seen a remarkable development in safety lamps for use in mines. Over a year ago in a competition held in England 195 different portable lamps were submitted and of these a number were accepted. Recently the British Home Office has approved of several new types.[56]

As the result of a prize competition in Germany,[57] a lamp has been evolved which is not only safe if broken but is also claimed to give indication of the presence of fire-damp. The principle on which the indicator is constructed is based upon the law of diffusive action. The indicator consists of a U tube containing a colored signaling fluid and so disposed that the presence of gas causes an obscuration of the light.

However, objections have been raised to this form of indicator based on the fact that it would not be operated upon by an explosive gas mixture, if this mixture were of the same density as the air.

In this country developments have proceeded along two lines, lamps designed for mines where fire-damp or other explosive gases are encountered, and those designed for mines such as metal ore mines where these difficulties are not encountered.

[55] *C. R.*, March 30, 1914, p. 394.

[56] *Elec. Eng.* (London), May 7, 1914, p. 253.

[57] *Elec. Times*, May 7 1914, p. 509; May 14, 1914, p. 536.

Three out of six lamps sent to the Bureau of Mines for test[58] were accepted for use in gaseous localities. These were of both the hand and cap service type. The following specifications have been issued by the Bureau:

Intensity of light at all times	0.4 cp.
Flux of light at all times	
Hand lamps	3 lumens
Cap lamps	1.5 lumens
Time of burning per charge	12 hours
Average life of bulb	300 hours
(Not more than 5 per cent. to have less than 250 hours.)	
Average life of batteries	3,600 hours
Variation in energy consumption of bulbs	10 per cent.
Angle of reflector	100 degrees

Acetylene.—For mines where the question of fire-damp and explosive gases does not have to be considered[59] the use of acetylene has been growing. Until recently the acetylene lamp has been developed for eastern mining conditions and has been of the hat or hand type. But in timbered mines the hat lamp is not used and recently an acetylene lamp has been brought out mounted in a hafted holder, so that the lamp can be positioned by sticking the haft into the timber or soft ground.

In this connection an effort is being made[60] to obtain an acetylene lamp for use in gaseous mines and in Geneva, Switzerland under the auspices of the acetylene associations of various countries a prize of $1,000 has been offered for a safety lamp that fulfils all requirements, both as to gas protection and technical and economical working.

STREET LIGHTING.

The constant demand for better public lighting is reflected in the increase in installations in some of the large cities of the country, during the past year. The luminous arc was being installed in large numbers up to the time of the introduction of the non-vacuum high efficiency tungsten lamp. There is already considerable evidence that the latter will be used in many places to replace the former.

Portland, Ore.—In Portland, Oregon there has been an in-

[58] *Elec. World*, December 6, 1914, p. 1165.
[59] *Acet. Jour.*, April, 1914, p. 409.
[60] *Acet. Jour.*, May, 1914, p. 425.

crease of 300 in the number of arc lamps with a decrease in rates of 7.8 per cent. for overhead arcs and 15.2 per cent. for underground. On one street ten blocks of display lighting has been installed consisting of arches at street intersections having a 1,000-watt lamp in the center, and 48 40-watt lamps in each arm of the arch.

Seattle, Wash.—Seattle claims to be the first city to try out the new non-vacuum lamps for street lighting.[61]

Los Angeles, Cal.—The constant growth in the use of automobiles has increased the demand for well-lighted roads outside as well as inside the city. A large boulevard system within fifteen miles of Los Angeles has been equipped with 375 tungsten standards,[62] and 600 will be required to complete the system.

Denver, Colo.—In Denver 100 new metallic flaming arc lamps have been put in, as well as 100 enclosed carbon arcs while in one street ornamental lighting has been installed to the extent of 102 standards carrying four 40-watt tungsten lamps each.

New Orleans, La.—New Orleans has increased the number of arc lamps used by 52 and installed 92 standards each equipped with a 200 candle-power series tungsten.

Galveston, Tex.—Galveston has installed 60 inverted arcs[63] on standards, six to the block.

Milwaukee, Wis.—In Milwaukee 200 inverted flaming arcs have been added,[64] rated at 3,500 candle-power and spaced 50 to 60 feet (15.24 to 18.29 m.) apart. In addition an ordinance has been passed authorizing a study of street lighting systems[65] to determine the one best suited to needs of the city.

Minneapolis, Minn.—Minneapolis has increased the number of magnetite arcs from 2,400 to 2,800[66] while the rate has decreased 4 per cent. One hundred gas lamps have been dropped.

Chicago, Ill.—The following table shows the progress in Chicago:

[61] *Elec. World*, January 10, 1914, p. 98.
[62] *Elec. World*, December 6, 1913, p. 1165.
[63] *Lt. Jour.* (U. S.), May, 1914, p. 108.
[64] *Elec. World*, January 24, 1914, p. 210.
[65] *Elec. World*, June 27, 1914, p. 1480.
[66] *Elec. World*, January 24, 191 , . 196.

	June 1, 1913	June 1, 1914
Arc lamps	17,084	18,973
80-watt tungsten lamps	814	4,433
Gas lamps	12,714	11,761
Gasoline lamps	7,845	5,120
25-watt subway lamps	302	4,409

Arrangements were completed, except for hanging, for the installation of 3,839 flaming arc lamps, but a trial installation of 2,000 of the new non-vacuum high efficiency tungsten lamps, 300-watt size, has replaced part of these. The cost of arc lamps not municipally lighted has remained the same. The cost of those under municipal operation, (depreciation and investment charges allowed for) has decreased 6.7 per cent. The municipally operated tungsten lamps decreased in cost 12.4 per cent. The cost of gas lamps dropped 2.8 per cent., while gasoline lamps operated under contract were renewed at a decrease in contract price of 3 per cent. per lamp.

The latest development (June 19, 1914) has been a decision to replace 1,000 direct-current open arcs and 6,000 7-ampere carbon arcs with the new tungsten units.

Detroit, Mich.—Progress in Detroit[67] is indicated by the addition of 240 4-ampere arcs on underground circuits and 575 of the same lamps on overhead circuits, as well as 100 inverted magnetite arcs at intervals of 159 feet (48.47 m.) measured center to center.

Washington, D. C.—At Washington, D. C. a number of series enclosed arc lamps have been replaced by the 6.6-ampere luminous arcs, the latter being mounted on standards especially designed for the purpose. But on the other hand 946 arc lamps, of various types have been replaced by 1,573 125-candle-power incandescent lamps and 206 80-candle-power lamps all on underground circuits. The number of gas lamps, 60-candle-power mantle type is 10,246 with a gradual yearly increase.

Philadelphia, Pa.—In Philadelphia the number of arc lamps used increased from 14,421 to 14,425 while there is a regular yearly increase of 300 in the number of gas lamps. The latter are provided free. The cost of arc lamps decreased 5 per cent. per lamp. Gasoline lamps remained unchanged in number and price per lamp.

[67] *Elec. World*, January 24, 1914, p. 212.

New York, N. Y.—New York City has increased the number of arcs from 19,430 to 19,634 the rates remaining the same except in the case of the 475-watt single flaming arcs where there was a decrease in price of 4 per cent. The number of incandescent lamps changed from 18,734 to 21,185 the rates remaining practically the same. Provision has been made to change the series incandescent lamps to the new non-vacuum lamps of 70-watt size.

Worcester, Mass.—Worcester, Mass. has installed 500 6.6-ampere luminous arc lamps[68] at distances of from 80 to 125 feet. (24.38 to 38.1 m.)

Boston, Mass.—In Boston[69] there has been a reduction of 14.8 per cent. in the cost of arcs, while Brookline[70] has made a beginning toward improved illumination by installing 45 luminous arc lamps.

France.—Abroad gas lighting maintains its popularity as a street illuminant.[71] In Paris in particular high pressure lighting has been making considerable gains as may be seen from the following table:

NUMBER OF LAMPS.

Year	500 cp.	1,000-cp.	2,000-cp.	4,000 cp.	Total
1910	—	7	68	29	104
1911	—	7	305	68	380
1912	—	38	315	117	470
1913	16	193	875	159	1,243

Great Britain.—High Pressure gas lighting has also made gains[72] in England and at Edinburgh, Scotland, an experimental installation of 16 lamps has been made. These have replaced 36 of the ordinary type. They are lighted and extinguished automatically and several have been provided with two burners, one of which is extinguished at midnight.

At Leeds, England[73] the high pressure system is to be extended. Glasgow has been extremely progressive on the street lighting question,[74] and there has been since 1895 an increase in the num-

[68] *Elec. World*, June 27, 1914, p. 1482.
[69] *Elec. World*, March 25, 1914, p. 685.
[70] *Elec. Rev. & W. E.*, November 27, 1913, p. 1010.
[71] *Jour. Gas Lt.*, June 16, 1914, p. 776.
[72] *Jour. Gas Lt.*, October 14, 1913, p. 140.
[73] *Jour. Gas Lt.*, October 14, 1913, p. 169.
[74] *Lt. Jour.* (London), May 1914, p. 230.

ber of gas lamps from 13,672 to 106,684 while electric lamps have been introduced to the number of 5,116. An interesting development in Glasgow,[75] has been the taking over by the municipality of the lighting of those private streets, closes, stairs, etc., which have been taken care of by private interests since 1866.

In London, 430 arc lamps have recently been added to the square mile embraced in the original city.[76] A distinctive feature of the globes is the inclusion of a dioptric lens to aid in the distribution of the light horizontally and downward.

Italy.—A pretentious program has been started in Turin, Italy,[77] where over $500,000 have been appropriated for improved lighting. For the main streets approximately 3,000 flaming arcs are to be provided, while the side streets will be lighted by incandescent lamps.

Specifications.—The question of street lighting specifications has been a prolific source of argument and difference of opinion for some years. A recent extended discussion in England[78] served only to emphasize the lack of unanimity on the part of lighting engineers as to just what the requirements are for satisfactory street illumination. The problem has been attacked in this country[79] by a committee appointed by the National Electric Light Association and the Association of Edison Illuminating Companies along lines somewhat different from those previously employed. It was assumed that the fundamental purposes to be served by street illumination are,

1. Discernment of large objects in the street and on the sidewalk.
2. Discernment of surface irregularities in the street and on the sidewalk.
3. Good general appearance of the lighted street.

Two actual streets were equipped for observation under working conditions and comparative tests have been developed to determine in these streets which of two streets lighting systems serves each of the above mentioned purposes the

[75] *Ill. Eng.* (London), May 1914, p. 228.
[76] *Elec. Rev. & W. E.*, July 28, 1914, p. 131.
[77] *L'Electricien*, March 28, 1914, p. 203.
[78] *Elec.*, May 8, 1914, p. 179.
[79] Report Committee on Street Lighting--National Electric Light Association, June, 1914.

better. In the past, tests of street lighting have been confined almost exclusively to photometric measurements either on horizontal or vertical planes or both. In the tests in question, observation was made the principal point of comparison, but complete photometric data were also obtained comprising the candle-power of the illuminants and measurements of the horizontal and vertical illumination and of brightness. Eight series of observational tests were made using as many as twelve observers who both riding and walking recorded their judgment on such questions as ability to see the faces of people met on the sidewalk, irregularities in the pavement, obstructions in the roadway, ability to read print, tell time, etc. The final results have not yet been obtained.

Public interest.—That the public is beginning to recognize the desirability of good lighting is indicated by the recent action of a club,[80] in one of the large cities, which appointed a committee to investigate the question of street lighting and make recommendations to the city council.

In another city a 'Municipal Lighting Day' was held at the State University[81] for the benefit of city officials throughout the state and for others interested in the conduct of municipal affairs. This included lectures and demonstrations on the subject of street lighting.

EXTERIOR ILLUMINATION.

The satisfactory results obtained in the artificial lighting of tennis courts has caused a considerable extension of this form of lighting. In England[82] covered tennis and squash courts have been artificially lighted, both with high pressure gas units and electric lamps.

The value of light seems to be more and more appreciated in every walk of life. An experiment in the use of artificial light to increase the output of a poultry farm[83] has resulted in a reported increase of 30 to 40 per cent. in the number of eggs laid. In the case of young incubated chicks, the use of light made them feed longer and thereby accelerated their growth during the winter months by a third.

[80] *Elec. World*, January 31, 1914, p. 368.
[81] *Elec. Rev. & W. E.*, February 14, 1914, p. 339.
[82] *Elec. Eng.*, (London), February 19, 1914, p. 101.
[83] *Elec. World*, December 27, 1913, p. 1330.

The growth of aeronautics has created the need of properly illuminated fields for rising and descending at night,[84] and various suggestions have been made and experiments tried to determine the most suitable method. A need has also arisen for illuminated signals and signs so that an aeronaut travelling at night may determine his location and avoid dangers in descending. In the case of signal lights on the machine themselves, it is evident that arrangements must be made to indicate not only the direction of travel in a single plane but also whether a rise or drop is contemplated.

It is interesting to note that the Port of London Authority has recently equipped the dock policemen with electric torches[85] to take the place of the old fashioned oil lanterns.

The logical development of the animated sign[86] has made its appearance in the use of moving vehicles carrying highly illuminated displays.

The lighting of Christmas trees in the home[87] is a custom almost if not quite as old as the use of the tree itself. A recent innovation adopted by many American cities at the last holiday season consisted of out-door 'community' trees, in all of which illumination was a conspicuous feature of the ornamentation.

In regard to display lighting in general there has been a decided increase in the number of buildings lighted on the exterior for display purposes. In the past there have been numerous cases of so-called 'outline' lighting, in which the lights showed the contours. A new method called 'flood' lighting is being introduced in which the exterior of the building is brilliantly illuminated by sources placed at a distance.

The use of high towers for street illumination purposes was discontinued some years ago. The system has been revived recently for use in lighting railroad yards.[88] Steel towers 100 ft. (30.48 m.) high and 12 ft. square (3.66 m.) at the base have been placed at 500 ft. (152.40 m.) intervals and equipped with quartz mercury-vapor arc lamps.

[84] *Licht u Lampe*, October 23, 1913, p. 838.
[85] *Ill. Eng.*, (London), February, 1914, p. 70.
[86] *Elcc. Rev. & W. E.*, April 4, 1914, p. 656.
[87] *Elec. World*, January 3, 1914, p. 28.
[88] *Elec. World*, July 11, 1914, p. 85.

INTERIOR ILLUMINATION.

Car Lighting.—Interest in improving the lighting of railway coaches and street cars continues[89] and is apparently growing. Indirect and semi-indirect methods are being studied. In one city twenty street cars have been equipped with three different semi-indirect systems in order to see which appeals most strongly to the public. There is a general recognition that bare lamps are bad and that it is well worth while to use reflectors.

The final report of the Committee on Illumination of the Association of Railway Electrical Engineers[90] contains among other conclusions that equally satisfactory results may be obtained with either the center deck or half deck arrangement of the lighting units; best results will be obtained with a spacing not greater than two seats apart. The elaborateness of the tests and the expense involved are a most gratifying tribute to the importance attached to better lighting in trains.

Store Lighting.—That the educational efforts of this society[91] are continuing to bear fruit is indicated in the lighting installation of a large department store. In this case the window lighting system was worked out with foot lamps and border lamps equipped with movable color screens, so that the quality of the light could be altered to suit the requirements. The main lighting, of the semi-indirect type, has also a modified color value. For the trying on of theatrical costumes, the foot lamps and border lamps are not only provided with means for color modification, but also with dimmers and a spot light is likewise available.

In order to eliminate the annoying reflections from the glass of show windows, a new system has been devised in which the window pane is made concave inward.[92]

Another novel application of the indirect lighting system has been made in the case of banks[93] where the lamps are contained in troughs along the bank rail over the teller's desks.

School Lighting.—During the course of an extended discus-

[89] *Trans. I. E. S.*, January, 1914, p. 25; *Rlwy. Elec. Eng.*, November, 1913, p. 249 and December, 1913, p. 264.

[90] *Report of Comm. on Illumination of Assoc. Rlwy. Elec. Eng.*, 1914.

[91] *Elec. World*, May, 24, 1914, p. 1134.

[92] *Tech. World*, July, 1914, p. 686.

[93] *Ill. Eng.* (London), January, 1914, p. 8.

sion before the British Illuminating Engineering Society[94] on the subject of daylight illumination in schools, it was brought out that as a minimum actual illumination on the desk for reading in the school room in full (midday) daylight, different authorities recommend from approximately 1 to 8 foot-candles. Among the new suggestions were, the determination of the 'sill-ratio', *i. e.*, the ratio between the illumination on the window sill of the school room and that on the desk most remote from the window, as a means of determining the access of daylight into schools; experiments to ascertain how far it is possible by using small models to predict the actual daylight conditions in an interior; and an 'indicator-photometer' as a means of signalling when the artificial light should be turned on.

In a later [95] interim report the following tentative suggestions were made:

> No place is fit for use in a schoolroom when 'diamond type' cannot be read easily by a normal observer at a distance of half a meter.
>
> The darkest desk in any schoolroom should receive an illumination equivalent to that derived directly from 50 reduced square degrees of visible sky. In these circumstances the place should receive not less than 0.5 per cent. of the unrestricted illumination from the complete sky hemisphere.
>
> The windows should be located in the wall to the left of the pupils, and the glass should be carried to the ceiling and not interrupted by cornices, pillars, or decorations.
>
> No desk in a schoolroom should be farther from the window wall than twice the height of the top of the glass above the desk surface.
>
> The ceiling should be white. The wall opposite to the window and the wall behind the children should be lightly colored from 30 in. (0.76 m.) above the desk level. The wall around or behind blackboards should be somewhat darker than the rest of the room.
>
> All furniture, desks, and surfaces in the lower part of the room should be finished in an unobtrusive color, dark shades and black being avoided.

It should be noted that there are some points in these suggestions on which more definite information is desirable, and further work on the subject will doubtless meet this need.

Church Lighting.—There is a growing tendency away from the

[94] *Ill. Eng.* (London), January, 1914, p. 15.

[95] *Ill. Eng.* (London), July, 1914, p. 365.

old belief that the interior of a church should be in a state of twilight illumination,[96] toward a realization that the church should be made cheerful and that this is to be accomplished by good lighting. For this purpose the indirect lighting method is growing in favor although the lower installation and operating costs, as well as the architects' influence, are responsible for the use of direct lighting in some cases even in new churches.

Picture Lighting.—The proper lighting of pictures has been a vexing problem with illuminating engineers for many years. While it is comparatively easy to see what is required for a single picture, to produce the result not only for one, but many has taxed the resources of numerous engineers and architects. At a recent Art Loan Exhibition an effort was made[97] to illuminate the pictures as far as possible by light coming from the right direction and also of the proper color content. Plain and colored lamps were used, placed in troughs above and in front of the frames and so arranged that no light was specularly reflected to the eye of the observer.

PHOTOMETRY.

Heterochromatic Photometry.—The branch of photometry which seems to have had the most attention during the past year is that involving the measurement of lights of different color. The continued increase in the temperature at which incandescent lamp filaments are being operated has served to accentuate the difference in color between these lamps and the carbon lamps used as standards.

The study of the flicker photometer has been continued.[98] Some recent experiments have been made indicating that the time element in the growth of color sensations will explain the reason for weighting red light more than blue-green light when comparing the flicker method with the direct comparison method. On the other hand, a comparison, using the two methods, of two lights of the same resultant color, one having a continuous spectrum the other made up synthetically, gave the same result in both cases.

The method of employing colored solutions as filters is well

[96] *Elec. Rev. & W. E.*, November, 1, 1913, p. 856.
[97] *Elec. Rev. & W. E.*, December, 13, 1913, p. 1127.
[98] *Elec. World*, May, 1914, p. 1105.

known. A recently described[99] application consists in the use of two wedge shaped glass cells, one of which contains copper sulphate, ammonia and distilled water, and the other iodine, potassium iodide and water. By properly varying the position of one wedge with respect to the other an infinite number of color changes can be produced in the light falling on the photometer and coming from the comparison source.

Still another method has been suggested[100] for use in heterochromatic photometry utilizing the extreme sensibility of the peripheral retina to brightness contrast. The apparatus includes a vertical screen with an opening at its center, a series of rotating measuring disks made up of sectors of grey and black in varying proportions, and a photometer bar.

Methods.—The use of fluorescence as an indicator of spectral radiation[101] forms one of the latest additions to the large number of photometric methods. Radiation from the two sources to be compared enters opposite sides of a vessel containing a fluorescent solution of known constitution and absorbing qualities. The point at which the intensity of fluorescence is the same is noted on a moving carriage.

The use of ruled gratings for cutting down intensity in photometric work was developed some years ago. A new modification[102] consists in placing one in front of another with their lines parallel. One grating is fixed and the other is movable by means of a graduated screw in a direction perpendicular to the lines. Thus an effective absorption is obtained from 50 per cent. to 0.

Photo-electric Cell.—The search for an objective photometer which shall take the place of the human eye in measuring light intensities continues but with questionable success.

Abroad a recent study of the photo-electric cell for this purpose gave apparently satisfactory results.[103] Filters were used such that the maximum sensitiveness occurred at the same point in the spectrum as with the human eye. Differences of not more than 6 per cent. were found when measuring the candle-power of various lamps with the cell and with an ordinary photometer.

[99] *Sci. et Art de L'eclair*, November, 1914, p. 163.
[100] *Elec. Rev. & W. E.*, March, 7, 1914, p. 478.
[101] *Zeit. f. Inst.*, November, 1914, p. 348.
[102] *Jour. f.. Gas*, May, 16, 1914, p. 457.
[103] *Elek. Zeit.*, April 30, 1914, p. 504.

Another investigation in which an effort was made to use the cell in measurements of sunlight[104] showed that for the measurement of very high intensities, cells of the vacuum type must be used.

The whole question of the practicability of the use of the photo-electric cell in photometry[105] has recently been thrown open, however, in consequence of the results of an investigation of gas-filled cells in this country which seems to show that this cell is not as satisfactory as has been considered. The illumination current relationship, formerly considered linear, is shown to be a highly complicated function of a number of factors.

The results of another investigation[106] indicate that the photo-electric effect of potassium is to be explained by the considerable gas assimilation of this material *i. e.,* that the existence of gas is a necessary condition for appreciable photometric effect. The correctness of this conclusion is questioned, however, in consequence of some later measurements[107] on freshly cut sodium surfaces in vessels containing residual gases and in others using an extremely high vacuum.

Selenium.—It has been hoped that the selenium cell might be the solution of objective photometry. But no advances in this direction have been made during the past year.

Some work has been done[108] indicating that selenium as such does not have a characteristic sensibility curve, and that differences in the characteristics of light sensitive selenium are purely the result of different crystal formations.

The effect of adding small quantities of tellurium[109] on the sensibility to light of a selenium cell has been studied. It was found that the presence of from 1 to 7 per cent. of tellurium as an impurity in the selenium made a decided difference in the sensibility curves of the cell to various monochromatic radiations in the visible. This is suggested as a possible explanation of the difference found by various observers in the relative position in the spectrum of the maximum of sensibility.

[104] *Phys. Zeit.*, June 15, 1914, p. 610.
[105] *Astro. Jour.*, June, 1914, p. 428.
[106] *Ber. der Deut. Phys. Gesell.*, No. 2, 1914, p. 117.
[107] *Phys. Rev.*, July, 1914, p. 73.
[108] *Phys. Rev.*, July, 1914, p. 48.
[109] *C. R.*, July 6, 1914, p. 41.

Spectrophotometry.—In spectrophotometry an improvement on the Brace type has been worked out.[110] In the older form changes in intensity on one of the fields were obtained by changing the slit width of the corresponding collimator. To obviate the errors introduced and the elaborate calibration required, polarization has been employed. Two nicol prisms are placed in that one of the collimator tubes the light from which is reflected from the silver strip portion of the dispersing prism. It is claimed that the ordinary difficulties arising from the use of polarization are eliminated.

Standards.—The question of light standards has not been agitated much and but little has been done looking toward the establishment of the ultimate primary standard.

The use of the Hefner lamp[111] as a standard is comparatively limited in this country, but abroad, particularly in Germany, it enjoys considerable popularity as evidenced by the last report of the Physikalisch Technische Reichsanstalt. During the year 1913 85 lamps were submitted for test, the total number submitted since the beginning of certification in the year 1893 being 2,079. In addition to the Hefner lamps, 78 carbon lamps were tested for use as photometric standards and 333 metal filament lamps.

At the National Physical Laboratory[112] in England the international comparison, through the United States Bureau of Standards, the Laboratoire Centrale in Paris and the Reichstanstalt in Berlin, of high efficiency incandescent lamp standards has been completed. Measurements made at the laboratory after the return of the lamps showed that their candle-power had remained constant enough to ascribe an accuracy of 0.25 per cent. to the results. The ratios obtained were as follows:

$$\frac{\text{Reichsanstalt}}{\text{Nat. Phys. Lab.} \times 0.9} = 1.00_0 \qquad \frac{\text{Bur. of Std.}}{\text{Nat. Phys. Lab.}} = 0.99_7$$

$$\frac{\text{Lab. Cent.}}{\text{Nat. Phys. Lab.}} = 0.99_8.$$

In these comparisons a color difference was entailed corresponding to that between a carbon lamp at low efficiency and a tungsten lamp at 1.25 watts per mean horizontal candle.

110 *Astro. Jour.*, April, 1914, p. 204.
111 *Jour. f. Gas.*, June 27, 1914, p. 622.
112 *Elec.*, July, 1914, p. 574.

A portable electric standard for use in measuring the candle-power of gas[113] employs a 4-volt tungsten lamp at 2 w. p. c. and is based on the property of tungsten of rapidly changing its resistance with change in current. The lamp is made one arm of a Wheatstone Bridge and is brought to its rated candle-power by changing a rheostat until the galvanometer gives zero deflection.

Glarimeter.—Under the head of photometry might be mentioned a new instrument called a glarimeter,[114] designed to measure the relative glare or gloss of paper. It was found by experiment that light reflected at an angle of 57.5 deg. from pieces of glazed white paper, calendered black cardboard, calendered white paper and brown solio paper showed a plane polarization 99 per cent. complete. It is a characteristic of most glass surfaces that light reflected from them at this angle, 57.5 deg., is almost completely plane polarized. The instrument, then, was designed to measure the glare by determining the fraction of the light reflected from the paper at an angle of 57.5 deg. which is polarized, the illumination falling on the paper at approximately this same angle.

An interesting test made with this instrument showed that the effect of passing a sheet of unsized newspaper through the calendering rolls twenty-nine times increased the per cent. glare from 27.7 to 64.8.

ILLUMINATING ENGINEERING SOCIETIES.

On the subject of photometric methods the German Illuminating Engineering Society has adopted the following definitions:[115]

"Evaluation of sources of light (special lamps excepted). A source of light is to be evaluated through one of three quantities—*viz.*, (1) mean spherical illuminating power (J_0); (2) mean lower hemispherical illuminating power ($J_{\smile}$); or mean horizontal illuminating power (J_h). Every statement must clearly indicate which of the three quantities is intended.

From the purely physical standpoint J_0 is the most important illuminating power. On practical grounds it is not generally feasible to give up the evaluation of $J_{\smile}$ or J_h, which has hitherto been customary.

It is therefore recommended that there should be added to the figures for $J_{\smile}$ or J_h the factor for their conversion into J_0."

[113] *Proc. Amer. Gas Inst.*, vol. VIII. 1913, p. 325.
[114] *Elec. World*, March 21, 1914, p. 645.
[115] *Jour. Gas Lt.*, July 14, 1914, p. 99.

These definitions have been adopted by the German Association of Gas and Water Engineers and the Institute of German Electrical Engineers.

No conclusions have as yet been reached on the question of nomenclature, but in England the 1910 report of the Committee on Nomenclature and Standards of the Illuminating Engineering Society (U. S.) has been made the basis of a considerable discussion. The results of this discussion, which was participated in by members in other countries, show that there is still a wide diversity of opinion on this subject and emphasizes the necessity of such a body as the International Illumination Commission to which problems of this character may be referred.

According to a published statement of Prof. A. Blondel[116] the effort to establish an illuminating engineering society in France has not been successful. This is apparently due to inability to obtain the moral support of the two large technical societies, one of gas and one of electricity.

INTERNATIONAL ILLUMINATION COMMISSION.

The most important advance in illuminating engineering as a whole came just before the last convention and was forecasted in last year's report.

At the fourth meeting of the International Photometric Commission[117] held in Berlin, Aug. 27, 1913, a re-organization was effected in which delegates from ten countries participated and formed the International Illumination Commission. The following officers were elected: President, M. Th. Vautier, France; Vice-Presidents, Prof. Hans Bunte, Germany; Dr. E. P. Hyde, America; Dr. L. Kusminsky, Austria; Hon. Secretary, Mr. C. C. Paterson, England; Treasurer, Mr. Weiss, Switzerland. The above officers with two representatives from each contributing country form the executive committee. The representatives of each country are selected by its national committee, if there is one. In default of a national committee societies interested may act directly, but in no case may more than 10 delegates be sent to represent any one country. French was adopted as the basic language.

116 *Sci. et Art de l'Eclair*, May, 1914, p. 158.
117 *Elec. World*, September, 3, 1913, p. 511.

As a result of this action there is now an authoritative organization which has for its object the study of questions relative to the lighting industry and the establishment by all appropriate means of international agreement on questions of illumination and to which may be referred such problems as international agreement on a primary standard of light; uniformity of nomenclature in illuminating engineering; definitions, standard photometric methods, etc.

In accordance with the requirements of the Commission a National Committee has been formed in Great Britain[118] composed of five representatives of each of the three technical societies and two from the National Physical Laboratory.

In this country a National Committee had been formed prior to the establishment of the International Commission. It was composed of two representatives from each of the following societies. The Illuminating Engineering Society, The American Gas Institute and the American Institute of Electrical Engineers, while the American Physical Society was informally represented. At a meeting held in February of this year statutes were adopted fixing the membership of the committee as follows: Not more than three representatives from each of the constituent technical societies, one representative from the Bureau of Standards. Any individual who represents the United States as an officer or member of the Executive Committee, or who is a member of any standing committee of the International Commission on Illumination and who is not otherwise a member of the committee. Any individual who actually represented the committee as delegate in attendance at the last preceding meeting of the International Commission on Illumination, and who is not otherwise a member of the committee. Furthermore, when for special reasons the committee desires the intimate co-operation of certain individuals, the committee may elect such individuals as members at large. The terms of all members at large shall expire at the time of the annual November meeting.

GLOBES, REFLECTORS AND FIXTURES.

Since the last report there has been a great increase in the variety of reflecting and diffusing equipment available for light-

[118] *Il Eng.* (London), January, 1914, p. 14.

ing. This increase has proceeded along artistic lines, along engineering lines, along the lines of special adaptation to particular needs, along the lines of higher and lower priced units and of larger and smaller units.

This increase in variety is particularly noticeable in the semi-indirect field. In selecting units to-day, the selection can be made from a much greater choice than was possible a year ago. There is also a tendency on the part of manufacturers to put out units which approach direct lighting in the results they give, as far as diffusion is concerned, but have the appearance of a semi-indirect lighting unit. This has resulted in the closing of the gap between direct lighting and semi-indirect lighting, as far as reflecting and diffusing equipment is concerned. This emphasizes the need of some other terms than indirect and semi-indirect to apply to lighting systems.

There is a greater tendency in the design of globes and reflectors to have them particularly adapted to architectural needs and particular classes of service. There is a greater variety of units corresponding to particular periods of architecture, and units designed especially for the lighting of churches, hospitals and residences are more in evidence.

From an engineering standpoint the most marked developments during the past year are those involving the use of semi-indirect fixtures for both gas and electric lights and in particular those which have accompanied the advent of the high candle-power and high efficiency gas cluster lamps and the non-vacuum tungsten lamps. The high intensities of these types has made the need for the use of diffusing globes more apparent than ever. In all the units put out for these lamps and the holding equipment for them, the ventilation is an important feature and in the case of gas lamps mica sheets are utilized to baffle the heated products horizontally and thereby prevent ceiling discoloration. Mica baffles are also used in gas lamps below the source to prevent over heating of the glassware. Another point of interest in the tungsten lamp is that the type of filament is much more concentrated than formerly and this is a distinct advantage in that it is possible to obtain higher efficiencies and better distributions of light than were formerly possible with much longer filaments.

In industrial lighting there has been a noticeable tendency in the direction of the increased use of deep bowl reflectors. In street lighting a prismatic refractor has been developed which gives a very extreme distribution of light, the candle-power being highest at about 75 to 80° from the vertically downward direction.

The extent to which the artistic in lamp fixtures has progressed is shown in the production of a dome made of china by a manufacturer of artware and dinner sets.[119]

Mention was made in last year's report of the use of marble in thin sheets to replace glass in lamp fixtures. A big improvement[120] in this material is shown in the production of plates ⅛ in. to ⅘ in. thick (3 to 20 mm.) polished on both surfaces and impregnated with various oils at high pressure and temperatures. In this connection a recent investigation of this material has shown that it is much more translucent than milk glass. The treated marble was found to transmit more red and much more blue than milk glass and is a good diffusing agent even though having a translucency of 40 per cent. The following table shows the results found on the translucency and diathermacy of these marble sheets as compared with various substances.

TRANSLUCENCY AND DIATHERMACY OF VARIOUS SUBSTANCES.

Thickness and material of interposed stratum.	Percentage of light transmitted.	Percentage of heat transmitted.
None	100	100
Treated marble 0.12 in. (3 mm.)	41	5.1
Untreated marble 0.12 in	21	4.9
Mica 0.02 in	33	67.5
Clear glass 0.08 in. (2.2 mm.)	92	80.0
Hard rubber 0.01 in. (0.3 m.)		51.7
Writing paper	27.5	4.8
Writing paper oiled	55	16.7
Milk glass 0.12 in.	25	16.6
Ground glass 0.12 in	76	40.6

A still further extension of the daylight duplication idea[121] is to be found in the development of spectacles made of colored absorbing glass fitted with a dyed film. Different spectacles are designed for different light sources, the materials used being

[119] *Elec. World*, May, 23, 1914, p. 1166.
[120] *Elek. Zeit.*, February. 19, 1914, p. 199.
[121] *Light. Jour.* (U. S.), February, 1914, p. 34.

the same as those which would be required in order to make an artificial daylight lamp out of the source in question.

Fixtures have also been designed[122] which give a light distribution in a room similar to that given by a window, thus imitating daylight distribution.

The importance of avoiding glare is being appreciated to such an extent that spectacles using colored glass have been devised for attachment to the visor of a base ball players cap.[123] They are instantaneously adjustable and should be of considerable help to the player when it is found necessary to look directly toward the sun.

PHYSIOLOGY.

The action of radiant energy which enters the eye, has been studied[124] showing the relative amounts of energy absorbed by the various eye media and how the amount of absorbed energy varies with the temperature of the source. Thus it was found that in the total eye about thirty times as much energy is absorbed per lumen of tungsten light as per lumen of light from a black body at 5,000°.

Some work on visual acuity under monochromatic light[125] from the middle of the spectrum as compared with ordinary daylight showed considerable advantage in favor of the former. Results were also obtained indicating that yellow-green eye glasses have a marked effect in improving visual acuity in very bright daylight.

The final results of the extended research of the Glass Workers Cataract Committee of the Royal Society,[126] to find a glass that will cut off as much as possible of the radiation beyond both ends of the visible spectrum and still be transparent to the visible, have been published. Glasses have been prepared that cut off more than 90 per cent. of the heat radiation, are opaque to the ultra-violet and sufficiently free from color to be capable of use as spectacles.

The relative hygienic effects of gas and electricity[127] when used for lighting purposes has again been made the subject of an in-

[122] *Light. Jour.* (U. S.), February, 1914, p. 99.
[123] *Pop. Mech.*, August, 1914, p. 175.
[124] *Elec. World*, October 25, 1913, p. 844.
[125] *Elec. World*, December 6, 1913, p. 1160.
[126] *Phil. Trans. of the Royal Society*, A 509.
[127] *Elec.*, May, 29, 1914, p. 309.

vestigation. The test room used was 2 m. high, 1.25 m. long and 0.6 m. wide and the results have been variously interpreted depending on whether the critic admits that conditions in a chamber of this size are or are not comparable with those in ordinary living rooms. Another more recent investigation[128] has been made using two rooms of about 57½ cu. m. in size.

LEGISLATION.

Distinct progress in settling a controversy which has been agitated for many years is seen in a recent parlimentary action in England.[129] The question of whether the quality of gas should be judged on a basis of its calorific or its illuminating power has been for a long time a prolific source of argument and discussion. Charters have been granted recently to two gas companies specifying a calorific standard as a basis for test. Unfortunately there seems to be still a decided difference of opinion as to just how this calorific standard should be specified, but doubtless this will be settled after further research.

In this country the Wisconsin Public Service Commission considered the matter some six years ago, while in New York the question is still under advisement by the New York State Commission, although it has been determined as the result of an extended and very careful series of tests, that there is no definite law between the candle-power and heat unit value of artificial gas. Hence it follows that in changing laws which specify candle-power, it will not be fair to adopt a specific factor to fix the calorific value from the value of luminous intensity.

On the thirteenth of October the results of the work of a commission[310] appointed to fix the units of heat, light, etc., were submitted to the French Academy of Sciences for recommendation before being put into laws for France. The bougie decimale is proposed for the standard of light and defined in accordance with the recommendations of the International Congress held in Paris in 1889.

Legislation with respect to headlights is mentioned under the latter caption.

[128] *Jour. f. Gas*, July, 11, 1914, p. 690.

[129] *Jour of Gas Lt.*, June, 23, 1914, p. 943.

[130] *L'Electricien*, November, 8, 1913, p. 304; December, 30, 1813, p. 398.

LITERATURE.

Two magazines have been started during the past year, which will contain articles on illumination. The Revue Belge de L'Acetylene et de la Soudure Autogene of Brussels is a magazine to be devoted to both the lighting and welding branches of the acetylene industry in Belgium.

Another Belgium publication is the Revue Electrotechnique, the official organ of an association connected with the Institute Electrotechnique of Brussels.

A department called "lighting methods" has been added to the *Journal of Electricity, Power and Gas.*

The following books have been published:

The Elementary Principles of Illumination and Artificial Lighting, by A. Blok.

Die Elektrischen Metallfadengluhlampen inbesondere aus Osmium, Tantalum, Zirkon und Wolfram, by C. N. Weber.

Die Fabrikation und Eigenschaften der Metalldrahtlampen, by N. L. Muller.

DISCUSSION ON DESIGN OF ILLUMINATED SIGNS.*

Mr. R. E. Cleveland: The fact that the question of electric sign advertising is one upon which relatively little scientific research has been done, makes Prof. Ford's paper of great value in opening a new line of thought on a subject which has heretofore been governed by more or less cut-and-dry methods. This field containing such large commercial possibilities should properly be guided to a greater or less extent by the findings of broad technical research. Prof. Ford's paper appeals to me more perhaps because I have been carrying on tests of a nature similar to his. As yet my results are but preliminary to a broad consideration of the subject but their similarity to those of Prof. Ford no doubt would make them of interest to you.

I have been investigating the subject for some time following a plan embracing both theoretical and more practical lines. This plan includes a determination of the effect on readability of all factors which enter into the design of the letters and further, includes an investigation of such practical problems as the effect of dirt, atmospheric conditions, the use of flat and glossy paints, etc.

For the determination of some of the fundamental principles relating to simple letters, I constructed what I call a letter photometer. This is a steel carriage, from which are suspended a black background upon which letters can be marked, and a showcase lighting unit to give even illumination of the background, the carriage being arranged to ride on two steel wires and to be moved from the observer's stand by means of cords and pulleys. With this apparatus I made tests on white cardboard letters and obtained curves showing the effect of varying the letter proportions.

One test was made for the purpose of determining the proper width of the line in the letter to give maximum readability. I found that with a letter of given height and length, the distance to which it was readable increased rapidly as the width of line was decreased, until a point was reached where the ratio of the letter height to the width of line was about 15 to 1, below which

* Continued from page 458 (vol. IX).

point the lines of the letter blurred into the background and readability decreased as the width of the line decreased.

Another test was made to determine the effect of increasing the length of a letter, the height and width of the line being held constant. My curves show that within a range of sizes in commercial use, the readability of a letter of given height increases directly with the letter length.

I made another set of tests to determine the effect on readability of increasing the spacing distance between letters. I tested seventeen groups of three letters each, selected to bring together letters of all kinds of contour. The curves from these tests show that the readability increases rapidly with the increase of spacing distance up to the point where the letters become individually unreadable.

This preliminary work was performed to determine some of the simple characteristics of letters and to pave the way for investigation with electric sign letters on which I am now engaged. In taking up this investigation with electric sign letters I have constructed some letters which will permit me to make variations in their dimensions. The letters of one set are so constructed that the lamps and the back of the letter can be moved in and out, and held at any desired depth. Another letter is constructed in a collapsible form so that the width of the lines of the letter can be varied. Other letters are arranged to allow the spacing of the lamps to be varied. With the aid of these and other letters, and by following a systematic plan, I hope to have at a future date some data which may be of further interest.

As Prof. Ford's results show, visual acuity is lessened by increasing the intrinsic brilliancy of the object viewed. Electric sign letters, being essentially lines of light contrasted against a background which is relatively much darker, fall inherently into the class of objects which when viewed give intense stimulation to the cones in the retina, and the resultant picture sent to the brain is blurred by the sympathetic action of adjacent cones. The visual effect of this optical phenomenon is the halation with which the letter is surrounded, and with small letters this is the

factor which tends to blur out the detail of the letter and make it illegible. It is therefore of benefit in designing letters to have available data showing visual acuity at the intrinsic brilliancies common in sign work and I believe Prof. Ford should be complimented for his pioneer work along this line.

Atmospheric conditions as you realize, is a matter that requires quite a lot of experimenting, that is, if results of any value are to be obtained. A rain storm will cut down the distance of the readability of a letter. And it is actually possible for a fog to increase the readability of a letter. If a sign is too bright a fog might reduce the intensity of the light, give the effect of frosting, and actually make it more readable. So I say that not a little depends exactly on the intensity of the light of the letters.

MR. L. G. SHEPARD: One other thing should be mentioned. The proposition of the illuminated sign can not be reduced to an absolutely scientific basis, because there is always the subject, the observer, and as Prof. Ford has shown no two observers are the same. The signs must be based on the lowest possible intelligence rather than the intelligence of the highly trained observer. As Prof. Ford has stated, we can't forget the subjective element in working out these questions.

PROF. ARTHUR FORD: I did not make any tests as to the effect of atmospheric conditions; practically all these tests were made in clear weather. There were some made when it was slightly foggy, but not to amount to anything. We did not have enough foggy weather. I suppose if we keep the test going for a year we might get enough foggy days so that we could get curves which would give some interesting information.

PHOTO-SCULPTURING AND THE USE OF LIGHT IN THE PRODUCTION AND ILLUMINATION OF SCULPTURE.*

BY J. HAMMOND SMITH.

Synopsis: The commonly known processes of photography and lantern projection are combined to (1) produce a photographic record of form by light reflected from the subject, which is illuminated by a projected screen image; (2) to utilize the projections from the photographic record, and the screen image as two intersecting systems of light beams, in the reproduction of the form originally photographed; and (3) to illuminate the finished sculpture by means of projected photographs. By this process, a record of form is quickly obtained by simply taking photographs of the subject. These records are permanent, and may be used at any time for the production and illumination of statuary of any size.

The object of this paper is to explain a new principle in the use of light in recording the forms of objects and the reproduction of these forms in plastic material. This new use of light involves the commonly known processes of lantern projection and photography.

THEORY AND PRACTISE.

We are all familiar with the action of light in photography, where a single camera is used. In Fig. 1, P and L represent the photographic plate and lens of camera respectively, and O the object to be photographed.

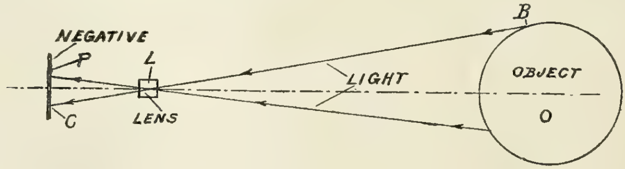

Fig. 1.—Plan of camera and object.

When the object is illuminated, light beams will be reflected in straight lines. A bundle of these beams is represented in line

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

B L C. They do not all pass through the optical center L of the lens, but they reach the same point C on the plate as if they had passed through on the straight line B L C. Thus innumerable points of the object O will be recorded on plate P, but the light beams which make the photographic record virtually travel in straight lines through the optical center L of the lens. Such a photograph is a record of one view of the object. Alone, it contains no record of form. Now if we place a projecting apparatus behind the negative (see Fig. 2), which has been removed, finished, and replaced, we have a reversal of the direction of light, and the recorded images on the plate are now projected outward, along the same straight lines C L B, and will form an image on a screen as B D, which will be similar to the image on the plate P. But this projected image alone cannot be used in locating points

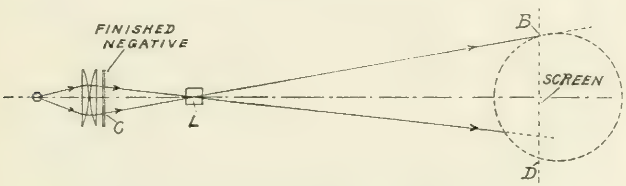

Fig. 2.—Plan of camera as a projector.

in space which were formerly occupied by corresponding points of the object photographed.

Now if two cameras (see Fig. 3), instead of one, be used in taking photographs, we have a double record of the object; or by taking the two photographs together, a record from two points of view. Now if these two photographs be finished and returned to their former places, and projected outward, as shown and described in Fig. 2, we have a means of locating particular points in space which were formerly occupied by the corresponding points of the object, when photographed. The two projected light beams from A and C will cross at B, because the light which formed the images at A and C emanated from point B. Therefore, if a screen, or other object, such as a lump of clay, be placed within the range of the beams of light, and moved back and forth until the two projected images coincide or superimpose, the position of the point in space is thus determined.

The location of any number of points may therefore be determined by this process, and the original object completely reproduced in form.

The process described in the preceding paragraph, while correct in theory, is not satisfactory in practise, because most objects which are to be reproduced do not have a sufficient number of well defined and recognizable points on their surface to allow the matching of light beams projected from the photographs and thereby the building of the statue with any reasonable degree of accuracy.

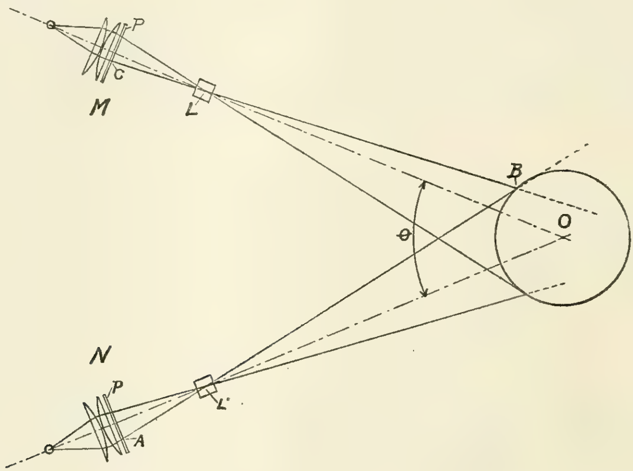

Fig. 3.—Plan of two camera-projectors and object.

In overcoming this difficulty, the process was not only improved, but also greatly simplified. By using only one of the cameras of Fig. 3, for photographing, and from the other, projecting a screen image as shown in Fig. 4, to illuminate the object to be reproduced, a record photograph as shown in Fig. 5 is obtained. In Fig. 3, suppose M to be the camera and N the projector from which the screen of Fig. 4 is projected. Now the object to be reproduced in statue being located at O, will receive certain marks or images. Taking a particular image, as the letter G, which is assumed to be located at A, the light beam passes from A in projector N to the object and is there reflected back through lens L, and forms an image of the letter G on the

photographic plate P, at C in camera M. (See Figs. 3, 4 and 5.) Now if this plate be finished and returned to its former position, and projected as described for other photographs, an image of the letter G will be found passing back along the line C L B, and will cross the beam A L B at B. Now if an object, such as a

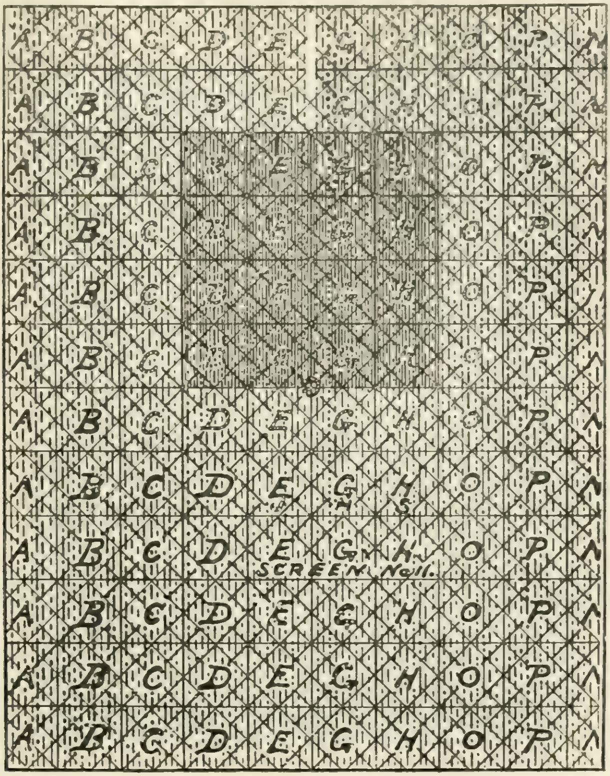

Fig. 4.—Illuminating screen, for record photographs.

lump of clay, be placed within the range of these two light beams, the two projected images of the letter G may be found and made to superimpose by moving the clay back and forth. When the two images exactly superimpose the surface of the clay occupies the same position as was occupied by the corresponding part of the model when the photographs were taken. In this manner we may proceed to build up or carve out the

reproduction by matching point after point of the two projections.

Fig. 6 illustrates the approximate matching of projected images on a bust. The white markings are from the record photograph (shown in Fig. 5) which was used in making the bust, and the black markings are from the screen (shown in Fig. 4). The surface of the bust is too near where the white markings appear on the right of the black markings, and vice versa.

In producing a complete statue, it is necessary to take a number (four to six) of photographs from various points of view, so that a complete record of the form of the object is obtained. This is accomplished by using a series of cameras and projectors, located in a circle about the object; or by mounting the object on a rotatable stand, with suitable stops, and using one camera, and one projector.

In building the statue, only the photograph which corresponds to the section of the statue being worked upon, together with the screen is used. The material from which the statue is to be made is mounted, and worked upon a suitable stand which takes the place formerly occupied by the object to be reproduced. The corresponding markings of photograph and screen are brought to coincidence by building up or carving down the material of the statue, as described in preceding paragraphs.

Any size of statue may be produced from one set of negatives, the taking of which require only a few minutes of the subject's time.

ILLUMINATION OF STATUARY.

The illumination of statuary, made by the process described above, is probably one of the most interesting features of the whole scheme. This illumination is accomplished by projecting colored lantern slides of the subject of the statue on the finished form of the statue. These lantern slides being made from ordinary photographs which are taken just after the record photographs, and while the subject is yet in the same pose. It will be readily understood that these illuminating photographs will exactly fit upon the statue, when projected, because they were made from a form which was exactly similar.

Fig. 5.—A record photograph.

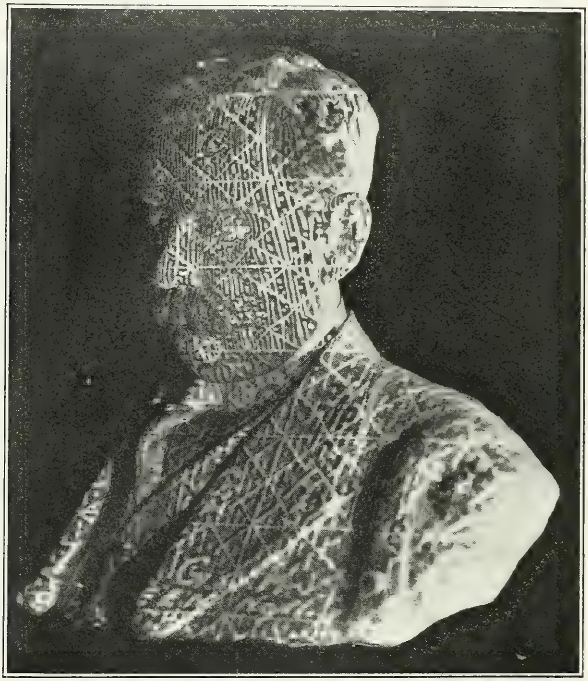

Fig. 6.—Photograph of a bust, with the screen of Fig. 4, and record photograph of Fig. 5 projected thereon in approximate coincidence.

We have here the combination of two likenesses, the photographic likeness combined with the likeness of form, these two producing a likeness which is little short of the actual appearance of the living person.

PRESIDENTIAL ADDRESS.*

CHARLES O. BOND.

At this the eighth annual convention of the Illuminating Engineering Society I wish, first of all in my capacity as president, to express for the Society our thanks to the City of Cleveland and to those good people in it whose cordial invitation and material support have led us to hold our convention here. I wish also to couple with this expression my personal thanks to that admirable group of men who, constituting the General Convention Committee, have made possible the excellent program of work and play listed before us.

The address which I have prepared is not given a name, but if it were entitled to a caption perhaps as fitting a one as any would be "A Miscellany." This miscellany will be composed of such thoughts and suggestions, intended for the society's welfare, as grew out of a year's intimate contact with its machinery and working forces.

In reading over former presidential addresses I was impressed with the number of suggestions made which have not yet borne fruit. One reason for this is that usually the man who makes the suggestions is passing out of office and his successor cannot be expected to be similarly minded as to the relative importance of the future activities in which the society might engage.

The constitution provides that "all committees shall be directly responsible to the Council and shall act under its direction." The appointment of committees, however, is in the hands of the president, and their period of office is co-extensive with his own. On the first of October each year, the Council in effect says to the new president: We expect you to find and appoint with our approval committee men live enough to accomplish in one year those things which in our opinion are worth doing, and the results of which, as we see them, the society can afford to sanction. When the president accepts such a challenge he is at once thrown on the loyalty of members. Consequently the extent to which any administration proves successful depends on volunteers.

* Delivered at the eight annual convention of the Illuminating Engineering Society Cleveland, O., September 21-25, 1914.

Believing strongly in the sub-division of responsibility, it seems best and fairest under such a case to empower a member who accepts a committee chairmanship to select as his own co-workers those who he believes will most help him during his year. This procedure results in more unity of action in a committee. It leaves the committee unhampered in its work, but places the responsibility for the society's approval of such work directly up to the Council.

The Society has been fortunate indeed this past year in the committees that responded. Evidences of their work are accumulating and have been shown throughout the year, as well as at this convention.

Of one thing we may be assured: while this Society has had most to do, as we believe, in starting an era of good lighting and illuminating engineering, it is quite unthinkable that such a movement now well under way would cease even were we to withdraw our influence. The movement will go on. Unless we feel that we have already fulfilled our purpose, it remains for us as a Society to make our impress upon this movement and to secure the fruit in prestige that rightly belongs to us by continuing constant in our duty.

But this brings up at once the question of whether the Society is constant in its whole duty. Our constitution states of the Society, "Its objects shall be the advancement of the theory and practise of illuminating engineering and the dissemination of knowledge relating thereto. Among the means to this end shall be meetings for the presentation and discussion of appropriate papers; the publication as may seem expedient of such papers, of discussions and communications; *and through committees, the study of subjects relating to the science and art of illumination, and the publication of reports thereon.*" It will be seen from this that we have two primary functions; first, to collect data and, second, to disseminate it. I wish to discuss briefly these two functions of the Society.

We have had numbers of papers printed on lighting installations, and several papers on practically identical lighting problems. The latter papers all had merit, yet they differed in the solution of the problem. In my mind it is from this point that

our Society must push on to more definite information. We have not thus far officially stated our criteria of good illumination; and if we do not, then others will attempt to supply them, and our prestige will suffer. Having proper criteria, it should become possible to standardize the illumination for a fixed case and to say from the requirements of that case: This is the approved solution of your lighting problem and the Illuminating Engineering Society stands back of it. You may rest assured that until other improvements in light sources or light modifiers have arrived, what we now state to you stands as the final solution. Such an action would mark a distinct gain for the Society.

It will be said that there are not on earth two things precisely alike, and that illumination requirements cannot be classified; but there are rows upon rows of houses in Philadelphia where I would defy anybody to distinguish one from the other save by the numbers or through training; and there are probably 10,000 office rooms in New York City that might each have been made to the same mold. These offices should normally require even more variation in their daylighting than in their artificial lighting, owing to the directional exposure; but if we could unite in an agreement upon the proper lighting of just one of these it would be so fairly typical of many others that a stand would have been taken on one definite type of installation.

It may be claimed that for five small rooms practically identical, five different dominant requirements exist. Very well. Let us still solve the five problems, each with as different a solution as is necessary, but with the accompanying statement of why each is right according to the criteria which we have adopted.

With the idea of the necessity of a single concrete decision in mind, a committee is under appointment to provide the best possible daylighting and artificial lighting for the council room in the headquarters at New York City. Large numbers of rooms exist of which this is typical. What we desire to accomplish is to have by all those who are qualified to judge on the subject a common agreement with the committee that, with the illuminants now at hand and accessories as they exist or can now be made, and with the office and its equipments as they exist, there shall have been put into effect in that single room in New York City

the best obtainable illumination. To my mind this would mark distinct progress by the Society.

This does not mean that other accomplishments of the greatest value are not already credited to the Illuminating Engineering Society such as the primer,[1] which teaches what to avoid; such as the exhibition booths, which show by contrast the value of improvement and what to admire; and such as the forthcoming popular lectures, with illustrations, which, when approved by the Council and given in such places as shall request them, will for each class treated, demonstrate bad and good lighting and seek to stimulate the interest of audiences in the general betterment of lighting. These as well as many other accomplishments of the Society in the past are excellent and admirable, but they lack the definite satisfaction that would result where *every method had been taken into consideration for a given case and the one best had been decided upon.* In doing this the Society would not seek to trespass upon the field of those who gain a livelihood by illuminating engineering. Quite otherwise; it would furnish them with more exact tools with which to work.

One of the embarrassments met by the members of this Society in the past when advocating good lighting has been to answer decisively the question in a given case "What is good lighting?" The man who makes this inquiry is a possible convert with enthusiasm to the aims of the Society; but when he states his simple question and sees a look of doubt creep into the face of the questioned member, because there has been no general agreement reached, there cannot help come into his mind at the same time a doubt as to the advisability of allying himself with a society which, as he sees it, does not beget definiteness of conclusion in its members.

The task of agreement upon the best illumination of a single room is not a simple one; it will result possibly in strife and contention; it involves the sacrifice of pre-conceived notions on the part of those who join in the agreement; it places one's name in the limelight for discussion; and yet with all of these drawbacks it is a thing which must be done and without further unnecessary delay.

[1] **Light: Its Use and Misuse.**

Some of our members are experimenting in their houses, perhaps in radically different directions upon proper methods of illumination. We are all waiting and hoping that some definite eye test will be produced which shall afford at least one of the necessary criteria for correct decision. For these reasons it will be thought by many that it is too early to presume to take a stand; but with me the belief is gaining solidity that after eight years of this Society's work in which the same problems have been present from the beginning, that the taking of this definite step may be due not so much to lack of information, or of methods of analysis, as it is due to a lack of courage. Every scheme which shall be suggested is susceptible of analysis and when analysis is applied the different qualities sought are bound to arrange themselves in an order of desirability.

I predict that if that sample room in New York City is lighted in the best possible way, as agreed upon, that it will become a mecca for those who have long desired a definite stand by some one, and logically by us, in this matter. Out of this will grow other attempts and decisions by our Society until finally a bureau of information will have come into existence available to those of our membership who, by every consideration of justice, are entitled to gain such information at our hands. So much for the collection of data.

Now as to the dissemination of information and of the growth of our Society through reaching new and larger audiences. When I speak of growth I do not necessarily mean growth in numbers, but growth in influence. Fortunately our sustaining membership scheme affords a possible means by which the influence of our society may be much extended, even if the individual membership does not grow to the huge members for which at one time we felt inspired to hope. In taking this point of view it is at once seen that the philanthropic feature of the society's work is strongly in mind.

What we seek is a wider publicity and acceptance of our message and, if I may use the phrase, a more diffused publicity. To interest a person we must teach him something new or which he accepts as helpful. It is not a simple matter in these days to find new things to present, although old things with occasional

success may be presented in new fashion. It seems quite as difficult to secure the adoption by others of things which are helpful, because in order that a thing shall be helpful it must be incorporated into the habits or surroundings of another person's life. Any educator or pastor can vouch for this non-adoption of helpful suggestions. Habits are fairly well fixed by the age of 19 or 20, and among these habits is the behavior of the individual towards light sources. By that age if he has acquired the habit of reading on a train by flitting sunlight, or facing specular reflection from his book or table top, there is some difficulty in breaking up these habits. You can tell him the old thing in your dozen new ways, but in as far as it reappears in his action you may have failed to cause so much as a hesitation.

There is an appeal, however, in which you will be imparting a new thing, because you will be saying it to a new individual, and this is by addressing yourself to a child. He is teachable, and the impressions which sink into his mind to-day remain the most vivid of his life. Every child who uses a piece of broken mirror to reflect the sun's rays into the eyes of people across the street is taking his first lesson in illuminating engineering. This is the time to catch him and to make your impression upon him. It should be the aim of this Society for this reason to put its primer into the hands of every teacher in the United States, so that through them its principles may be instilled into the minds of these children. Through them you will succeed in getting a message into the home of adults, even if you have failed a dozen times before. This primer in attractive form, with brightly colored binding, should hang in the school room where it can be freely consulted, both by the teacher in giving extracts from it and by the pupils as they grow to feel an interest in it. With the primer might be given a small pamphlet outlining simple experiments to be made with inexpensive apparatus by which the principles of good lighting are driven home. You may be sure the child will go home an avowed iconoclast and curiosity will be stimulated in that house, as to what good lighting means.

The census of 1910 shows in this country 595,306 teachers and 18,009,891 pupils, or about 30 pupils to a teacher. There have already been printed for circulation over 300,000 of these

primers, besides the extensive copying and comment which have followed in the technical journals and in some daily papers. I venture to say, however, that it would be difficult to find any appreciable effect of these upon the child, as he was not aimed at in the distribution.

Another form of publicity could be procured by our different sectional papers committees. This past year they have given excellent evidence of preparedness in having programs for the entire year appear in most cases at their early fall meeting. We must not lose sight of our missionary character in these programs and this suggests that each year, at least one meeting of the section should be devoted chiefly to those unfamiliar with our aims and that special efforts be made on that occasion to have an audience of that character present. We members should not attend that special meeting for what we can get out of it, but for what each of us can individually put into it, to effectually interest the audience in our propaganda.

Another means of extending our influence would be through a general publicity committee. I have noticed that during each year, among the many papers which reach our TRANSACTIONS some are of such value either through timeliness, point of view or pioneer quality, that they are eagerly copied or reviewed in technical journals. This same subject matter would have been keenly interesting in popular periodicals having a nation wide circulation, had the text been popularized and properly condensed. It would expand the influence of our Society if in such cases on the initiative of the Papers Committee, arrangements could be made between the author and a general publicity committee to have such a text prepared for these periodicals in which due credit would be given both to the author and to the Society.

It will be asked, where shall we get the money to carry on this expensive missionary work? I believe that if we demonstrate our faithfulness in the wise distribution of our funds, in the accumulation of useful data and in its beneficial dissemination, fulfilling carefully and impartially our mission as intermediary between the light producer and the light user, we shall be amazed at the growth in number of our sustaining members. This class

of membership in this country thus far has been composed almost exclusively of lighting companies and those engaged in the manufacture of lighting appliances. I see no reason why we should not have sustaining memberships from the different municipalities, certainly those exceeding 25,000 inhabitants, and from educational boards, philanthropic endowments and from private benefactors. That this is not merely a hazarded guess is shown by the fact that two cities, or their representatives in official capacities, have already taken out sustaining membership.

While we should look forward with great pleasure to bringing this message to the children, we must not forget our opportunity, even our duty, in other directions where we can be of service. It is gratifying to know that the advice and assistance of this Society are being asked in matters which pertain to the health and safety of groups of citizens. One of the latest calls of this kind to arrive was from a certain association, with reference to the eyestrain caused them through the use of a certain kind of envelope now very much in vogue.

As a society standing for proper industrial lighting and using our influence to secure it, it is well for us to consider from an indirect viewpoint our part in conserving the race. The 1910 census report contains the following table by decades relating to those persons above 10 years of age in gainful occupations in the United States. The figures show for each sex percentages of the total from 10 years up, so engaged.

	1880 Per cent.	1890 Per cent.	1900 Per cent.	1910 Per cent.
Male	78.7	79.3	80.0	81.3
Female	14.7	17.4	18.8	23.4

It will be noted that while males so engaged increased in 30 years 2.6 per cent., females increased 8.7 per cent. and that there was a 4.6 per cent. increase among females in the last decade alone. The occupations into which these extra women and girls have gone involve in most cases continuous use of the eyes and in many cases under very trying circumstances. The toll from nervous breakdown among these is heavy, unfitting or disinclining them for motherhood.

The average American family is composed of 4.5 persons, and

with 24 per cent. of the women of the land engaged in gainful occupations as above outlined, we can see our opportunity in pointing the way to improvement in the many atrocious installations of industrial and office lighting that now exist.

Since our last convention we are called upon to mourn the death of three highly esteemed members: Mr. Francis R. Frost, Topeka, Kan.; Mr. G. H. Hoffman, Philadelphia, Pa., and Mr. R. V. Scudder, St. Louis, Mo.

Within the past fortnight I have the word of a Japanese gentleman visiting in the United States, that Japan is soon to have an illuminating engineering society. This we shall be glad to welcome into the sisterhood of such societies. We deplore the European war, which for a time will lessen the activities of our sister societies in England and Germany and which may nullify the work of those who were laying the foundation of one in France. Because of the setback in Europe of these societies the duty lies the more heavily upon us to keep our torch burning brightly as a beacon by which they may again make port when out of their sea of troubles, and as an evidence that within our own coast progress, for them as well as for ourselves, is still in the making.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 6, 1914

PART II

Miscellaneous Notes

Section Notes.

In the next issue of the TRANSACTIONS will be published section programs of meetings and papers for the coming season.

The officers of the several sections for the season 1914-1915 are as follows:

Chicago Section: W. A. Durgin, chairman; H. B. Wheeler, secretary; managers: Harry S. Gradle, M. G. Lloyd, F. A. Pinckney, Edward G. Pratt, and Herman V. Willman; vice-president representing section on national council, F. A. Vaughn.

New England Section: Louis Bell, chairman; S. C. Rogers, secretary; managers: C. M. Cole, J. W. Cowles, Walter B. Lancaster, H. F. Wallace, and R. C. Ware; vice-president representing section on national council, C. A. B. Halvorson, Jr.

New York Section: Norman Macbeth, chairman; Clarence L. Law, secretary; managers: George W. Cassidy, Norman D. Macdonald, H. B. McLean, Frank E. Wallis, and Percy S. Young; vice-president representing section on national council, George H. Stickney.

Philadelphia Section: H. A. Hornor, chairman; L. B. Eichengreen, secretary; managers: James Barnes, Douglass Burnett, George S. Crampton, R. B. Ely, and F. H. Gilpin; vice-president representing section on national council, George A. Hoadley.

Pittsburgh Section: G. W. Roosa, chairman; S. G. Hibben, secretary; managers: W. A. Donkin, H. S. Hower, Harold Kirschberg, E. B. Rowe, and R. H. Skinner; vice-president representing section on national council, Ward Harrison.

Eighth Annual Convention.

The eighth annual convention of the Society, which was held in Cleveland, Ohio, September 21-24 inclusive, at the Hollenden Hotel, was a splendid success. Twenty-nine papers were presented. On one day parallel commercial and scientific sessions were held. The discussions were numerous, lively and interesting. About three hundred members and guests registered. The entertainment features were especially pleasing and provided a nice balance between work and play. The papers and discussions will be published in succeeding issues of the TRANSACTIONS.

New Officers.

The following new officers have been elected for various terms beginning October 1, 1914: president, Dr. A. S. McAllister; vice-president representing Philadelphia Section, Prof. George A. Hoadley; vice-president representing Chicago Section, Mr. F. A. Vaughn; vice-president representing New England Section, Mr. C. A. B. Halvorson, Jr.; directors, Dr. E. M. Alger, H. Calvert and V. R. Lansingh. The president is elected for one year, the vice-presidents for two years, and the directors for three years. The names of the members of the Council for the year 1913-1914 appear on the inside front cover page of this number of the TRANSACTIONS.

Since the election of the officers in May last, Mr. V. R. Lansingh, director, has tendered his resignation. Mr. Alten S. Miller has been appointed to succeed him.

TRANSACTIONS
OF THE
Illuminating Engineering Society

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VOL. IX — NUMBER 7 — 1914

MIXED SPECULAR AND DIFFUSE REFLECTION.*

BY P. G. NUTTING.

The reflecting properties of papers and of various other materials are being considered more and more by manufacturers and users, and the proper specification and measurement of these properties are becoming of interest to physicists and illuminating engineers. A nomenclature of the subject is becoming crystallized and various methods of determining specular and diffuse reflection, occurring together, have been developed. It is a fitting period to consider which are the best methods of measurement, what reflecting properties of materials are the most desirable and which of the newer terms proposed are most worthy of adoption.

The older methods of studying mixed reflection consisted essentially in measuring the relative surface brightness in various directions and then integrating the distribution curve. With proper attention to illumination, this method is capable of giving correct results and fairly complete information about the surface studied, but it is far too laborious for a practical working method.

In cases where distribution data are desired, in testing projection screens for example, perhaps the simplest method is to illuminate with a nearly parallel pencil of light nearly normal to the surface, determine the distribution of the reflected light with an illuminometer, and then the mean reflecting power with an

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

Communication No. 20 from the Research Laboratory of the Eastman Kodak Co.

[1] TRANS. I. E. S., vol. VII, p. 412.

[2] Lehmann, H.; *Ber. Ph. Ges.*, 11, 4 and 5, 1911.

absolute reflectometer.[1] This method has been in use for some time in the laboratory of the Eastman Kodak Company, Rochester, N. Y. Lehmann[2] has published distribution data on a number of Zeiss projection screens.

In most practical work, data on distribution are not required, only total specular and diffuse reflecting power separately. The glossiness or matness of a surface is defined in terms of these two reflecting powers. There are surfaces, it is true, for which it would be difficult to precisely define specular and diffuse reflection, rough water illuminated by both sun and sky for example. But the surfaces in which illuminating engineers are chiefly interested are mostly such as are easily specified and tested. The chief type forms of mixed reflection were described and illustrated to this society two years ago.[3]

Several methods have been used to determine specular reflecting power as a whole without resorting to a distribution curve. Probably the simplest is to determine total reflecting power and diffuse reflecting power separately and take the difference. If the diffuse reflection is measured perpendicularly with illumination at an angle of 45 deg. or more, all the light specularly reflected is thrown out of the field and a maximum value for the specular reflecting power will be obtained.

Other methods make use of the fact that the specularly reflected light is almost completely plane polarized while the diffusely reflected light is quite unpolarized. Of the polarization methods, probably the best is that used by Ingersoll[4] in the construction of his so-called glarimeter. In this the area and distance of the source of illumination and the angle of incidence are fixed and relative brightness determined by viewing through a nicol prism in two different positions.

An earlier but less precise polarization method is a by-product of the use of the author's absolute reflectometer. In using this instrument reflecting powers are determined with a Martens polarization photometer in direct and reversed positions, the two determinations differing by the amount of the specularly reflected polarized light. The method is objectionable in that reflection occurs at all possible angles of incidence, but I have recently

[3] Nutting, P. G.; TRANS. I. E. S., vol. VII, p. 616.

[4] *Elec. World*, March 21, 1914.

intercompared all three methods on pieces of very glossy paper and obtained results agreeing to within the uncertainty in the best determination.

The method of determining diffuse and total reflecting power separately is essentially a laboratory method in that it requires expensive instruments. It is, however, simple, rapid and precise.

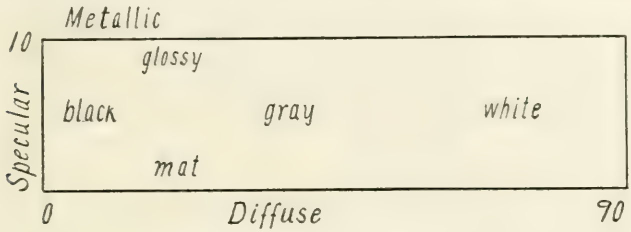

Fig. 1.—Mixtures met with in practise.

Ingersoll's method is probably best adapted to practical testing, while the total reflectometer method will prove useful in connection with total reflection work.

Measurements on mixed reflection give specular reflecting powers ranging up to 10 per cent. and diffuse reflecting powers from 0.5 to 90 per cent. in practically all combinations. A surface reflecting little, specularly appears quite mat whether accompanied

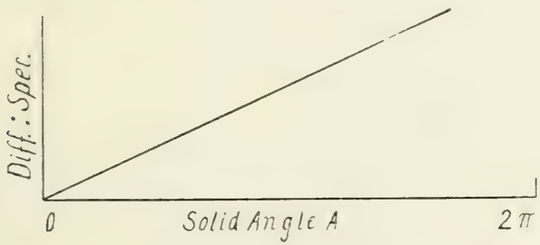

Fig. 2.—Relative brightness and angular area of source.

by 1, 50 or 90 per cent. of diffuse reflection. A moderately glossy surface reflects about 1 per cent., while very heavily glazed papers and porcelains reflect as high as 10 per cent. specularly. A specular reflection of over 20 per cent. appears metallic and occurs not only on the surfaces of metals but of dense dyes and of transparent substances giving total reflection. The surfaces of photographic papers are graded as mat, semi-glossy or velvet and

glossy. Surfaces are considered black, dark gray, light gray or white according to diffuse reflecting power.

The proper specification of glossiness is indicated by the methods and practical results discussed above. The most scientific is perhaps to give both specular and diffuse reflecting powers separately. A tabular list of possible practical definitions follows:

"Glossiness"	Range per cent.
Specular reflecting power (total less diffuse)	1.5 - 10.0
Ratio specular to diffuse reflecting power	0.01-100.0
Ratio specular to total reflecting power	0.02- 1.0
Ratio specular to diffuse brightness for source covering unit solid angle	0.01-100.0
"Matness"	
Ratio diffuse to total reflecting power	0.1 - 0.99
Ratio diffuse to specular reflecting power	0.1 -100.0
Ratio diffuse to total brightness for source of unit solid angle	0.1 - 0.99

It is, perhaps, most logical to define glossiness as the ratio of specular to total (specular plus diffuse) reflecting power and similarly matness as the ratio of diffuse to total reflecting power. 'Percentage glare,' defined as the ratio of specular to diffuse reflecting power, is open to serious criticism.

Glare is, of course, not a property of the surface itself, but refers to the appearance of a surface to the eye under certain illuminations. Of the various terms—glare, gloss, glossiness, matness, luster, sheen, shininess—relating to the amount of specular reflection from which one or two might be formed for general adoption, those used in the above table appear to the author to be most suitable.

Relative brightness under a specified illumination is a quantity closely related to direct observation and hence to be favored in practical works specifications. In a mixture of purely specular and purely diffuse reflection the apparent specular brightness is that of the source times the specular reflecting power of the surface, $B_s = B_o \times R_s$. The apparent brightness due to diffuse reflection is $\pi B_d = B_o \times R_d \times A$, where A is the solid angle (area/distance squared) subtended by the source of illumination at the surface in question. Hence, the ratio of diffuse to specular brightness is the ratio of reflecting powers times the solid angle subtended by the source of illumination:

$$\frac{B_d}{B_s} = \frac{R_d}{R_s} \cdot \frac{A}{\pi} .$$

Contrast is relative total brightness. Call this C, then

$$C = \frac{B_d + B_s}{B'_d + B'_s} = \frac{R_d A + \pi R_s}{R'_d A + \pi R'_s},$$

the primes referring to the part of the surface whose contrast is specified. Take the case of ordinary glossy print paper and ink. The diffuse reflecting power of the paper, $R_d = 0.80$, of the ink, $R'_d = 0.05$, say; specular reflection, $R_s = R'_s = 0.05$, say. Then

$$C = \frac{0.8A + 110.05}{0.05A + 110.05}.$$

$A = 0$	1	2π
$C = 1$	4.6	11.0

In words, for a small or distant illuminant ($A = 0$, direct lighting), the print may appear as bright ($C = 1$) as the paper; with good window lighting ($A = 1$) the contrast is 4.6 to 1, while with open sky illumination ($A = 2\pi$) the contrast is 11 to 1. Other contrasts may be as easily computed from known data by means of the above formula.

This paper grew out of criticism in the *Electrical World* of Prof. Ingersoll's paper describing his "glarimeter" for determining relative specular brightness. It was hoped that a discussion of methods, specifications and nomenclature would bring about an improvement in all them.

DISCUSSION.

Dr. P. W. Cobb: I am more than interested in this subject that Dr. Nutting has brought up, more especially for the reason that he brings in the question of brightness and contrast, because brightness is the final photometric quantity that determines the character of surfaces as visual objects and their contrasts, one with another. We cannot stop short of that in specifying a surface as it affects the eye. It is interesting to know that photometrists and especially illuminating engineers, are becoming interested in this question and are adapting their instruments to measure the brightness of the various surfaces in the space illuminated. Such brightness measurements seem to me to be data of great value in illuminating engineering, along with illumination data as ordinarily taken.

I want to ask one or two questions. I am a little in doubt

where Dr. Nutting takes up the mathematical portion of his discussion toward the bottom of the fourth page. Should not A be $\frac{A}{2\pi}$? If I remember correctly, it is a mathematical fact, that when a surface of 100 per cent. diffuse reflection is illuminated by a source of maximum angular extent, *i. e.,* by a uniformly bright hemisphere, the solid angle subtended by the source is 2π and the surface is just as bright as the illuminant. I want to ask if Dr. Nutting's statement should read that way or does the coefficient, R_d cover the factor $\frac{1}{2\pi}$? I would also like a little further elucidation of the question of specular reflection. My impression is that for a good many surfaces, such as paper, the specular reflection is itself more or less diffuse. If we should take a mirror of given area, break it into small pieces, take half of these pieces and cement them together in the same area with plaster of paris, they would not all be quite plane with the general direction of the surface; there would be slight angular variation, with the result that the specularly reflected light would be to a certain extent diffused. Do not most papers for instance, which give indefinite specular reflection, behave as such a mosaic of minute mirrors? It would be interesting to know if the calculations Dr. Nutting makes take that into account. I should think it would be of influence and would alter the apparent angular extent of the source as seen in the reflecting surface, and hence the brightness of the surface due to specularly reflected light.

Dr. M. G. Lloyd: Dr. Nutting has given us some numerical illustrations here showing for ink on paper that the paper may have up to 11 times the reflecting power of the ink or down to equality, so that in a certain light one is not able to discern the ink on the paper at all. Mr. Cravath, in a paper before the Chicago section, showed an interesting case where ink had a specular reflecting power even higher than that of the paper itself, so that when one gets the light in the proper direction upon it, the ink actually appears bright against the paper's less bright background. Thus the conditions are reversed from what they are ordinarily. This subject is very interesting to me, especially with reference to the visibility of reading matter. This is one

of the places where, as Dr. Nutting points out, we are not able to standardize anything yet because we have not yet got the definitions which must be at the basis of the standards, and it is a thing that I think the Society ought to take up. We should establish some definite definitions so that we can go ahead and discuss it more fully from a numerical standpoint; which we cannot do until we have some definite standard and some defined terms in which to express ourselves.

MR. M. LUCKIESH: The illuminating engineer might have two or three different view-points regarding the matter of specular reflection. We need some standardization regarding it. Among paper manufacturers or publishers there ought to be some way of setting a limit to the amount of specular reflection permissible. A means of determining or defining glossiness would involve the relative *brightnesses* of the glare spot and its surroundings; and for that reason I think that Prof. Ingersoll's instrument mentioned by Dr. Nutting measures just the thing wanted, the ratio of the brightness of the glare spot to the surrounding brightness. But I want to sound a warning as to the limitation of the definition or the measurement of glossiness even in this way. Glare from paper depends largely upon how the paper is illuminated. Paper such as we have here in the advance copies (a machine finished paper with very little calendering) would be quite free from glare if illuminated by a source of large area; whereas under such lighting conditions as are in this room (direct lighting, dark surroundings) there is considerable glare.

Lighting experts should understand that the brightness due to specular reflection depends very largely upon the brightness of that which is being reflected, because it is more or less an image of the light source, whereas the brightness due to diffusive reflection depends upon the distance from the source regardless of its brightness. I think there is more or less confusion as to just what glare from paper is; there seems to be no doubt however that it is due largely, to contrasts in brightness. As Dr. Lloyd pointed out, the ink will change the reflecting character and in a good many instances the letters can be actually distinguished

by specular reflection under which condition they are often brighter than the background.

Dr. P. G. Nutting (In reply): I quite agree with Mr. Luckiesh's statement that it is relative brightness (specular and diffuse) and not relative reflecting power that is of practical importance in estimating glare, but as stated in the paper and emphasized by him, relative brightness means nothing unless the solid angle subtended by the source be specified or some standard angle assumed.

Wavy specular surfaces and the surfaces composed of minute plane mirrors cited by Dr. Cobb are as easily investigated experimentally as any others provided they are not too coarse grained. The theory of diffusion caused by minute reflecting spheres and by minute plane mirrors I discussed in a paper read at the Niagara Falls convention two years ago. The specification of the diffusion caused by wavy specular surfaces and by any very coarse grained diffusion such as sunlight on rough water must be an arbitrary matter. In reading the paper I neglected to speak of the omission of the quantity π in the contrast equations at the end and I am obliged to Dr. Cobb for calling attention to it.

Dr. Lloyd points out the crying need for new fundamental definitions of luminous quantities in dealing with this subject, and I feel that the case cannot be put too strongly. It is patent to anyone that in dealing with imperfectly diffusing surfaces we cannot properly use any system of units involving assumptions as to point sources or the validity of Lambert's law. We trust that our esteemed Committee on Nomenclature and Standards will soon favor us with a system of units capable of any desired degree of generality or rigidity.

COLOR PHOTOGRAPHY.*

BY M. C. RYPINSKI.

Although experimental attempts to fix the colors of nature upon photographic plates and paper have been made for the last one hundred years, the development of color photography as it is known to-day dates back only about forty years. This paper deals chiefly with this period of development. No attempt will be made to cover the important fields of multi-color process printing and color kinematography; these and other kindred subjects not fully considered here are exhaustively treated in one or more of the publications listed in the appended bibliography.

While the problem of producing photography in color upon paper has not been satisfactorily solved from the standpoint of the average individual, it is true that there are several commercial processes available which will yield very good results, and the complete solution is surely not many years distant.

On the other hand, color plates for use as transparencies and as lantern slides for examination in the hand or on the screen by transmitted light have reached a high state of perfection; there are available several commercial plates which may be manipulated with a minimum of time and trouble by the average individual.

In approaching the subject it is desirable to review briefly some of the properties of light, and particularly its action upon the eye and the light sensitive emulsions going to make up the photographic plate or paper surface.

Light, according to the undulatory theory, is a sensation produced on the retina of the eye by a wave motion of the ether, all light travelling with the same velocity, the difference in color sensation being due to differences in wave-length and frequency.

* A lecture given at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

Daylight, or white light, is a combination of color sensations and may be broken up as by a prism or a diffraction grating into its component spectral colors, red, orange, yellow, green, blue, indigo and violet.

Of these color sensations the red has the greatest wave-length and the lowest frequency. The wave-length decreases and the frequency correspondingly increases as the violet end of the spectrum is approached.

Beyond the red is an invisible portion of the spectrum, the infra-red, and correspondingly beyond the violet there is the invisible ultra-violet, both of which are characterized by their chemical action upon light sensitive substances.

When rays of light encounter an object they are affected so far as color is concerned in two ways: first, by reflection; second, by absorption. That is, there exists a property in matter which causes a reflection from its boundary surfaces of rays of certain wave-lengths and frequencies, and absorption in its mass of rays of certain other wave-lengths and frequencies. All other rays pass uninterruptedly through its mass.

An opaque object is one which reflects or absorbs all light falling upon it. A transparent or translucent object, on the contrary, allows some light to pass through more or less unchanged. For example, a blue blotter has an opaque blue appearance under ordinary white light because it absorbs mainly red and green and reflects mainly blue, transmitting no light; in red or green light it would appear quite black. A pane of clear window glass transmits all the primaries, red, green and blue, absorbing practically no light; white light therefore entering on one side emerges unchanged on the other. Cobalt glass looks blue by transmitted white light because it absorbs red and green, leaving the blue to emerge practically unchanged. An object, due to its particular reflective and absorptive properties, may, therefore, have a very different appearance when viewed by transmitted light as compared with reflected light, and its appearance will of course vary with the color of the light source.

Another variable is the color sensitiveness of the human eye.

The normal eye sees all colors, but about 4 per cent. of all individuals are color-blind and lack the power to distinguish color in certain parts of the spectrum, generally the red end. In rare cases no color sensation exists at all, all objects appearing white or gray in tone.[1]

Clerk Maxwell has shown that all color combinations may be reproduced by a mixture of not more than three primary colors, red, green and blue.

Painters and printers are accustomed to regard red, yellow and blue as the three primaries, but this is due to their working with the subtractive method of color combination, where colors are laid one on top of another so that the resultant color is the original or light source color, less all of the colors which the various color layers have the property of absorbing.

In addition to the subtractive method of color combination, there is the additive method by which the final net result is the sum of all the color components used.

While most painters use the subtractive method, there is a school of painting in which the color is laid on in the form of little dots arranged side by side. This additive process gets its color combination from the inability of the eye to distinguish minute objects distinctly at a distance, the dots merging and forming a combination image of a color resultant which is the sum of all the colors of adjacent dots.

Another characteristic of colored light which plays an important part in color photography is the difference in its action on the retina and its chemical effect upon a photographic plate.

It is required of a photographic image that it shall duplicate in proper light relation the object as seen by the eye; however, the ordinary plate or film emulsion is insensitive to the infra-red and yellow portions of the spectrum, fairly sensitive to the green, quite sensitive to the blue and highly sensitive to the ultra-violet portion. An object therefore illuminated by the uninterrupted light of a bright portion of sky (which is largely composed of ultra-violet) will show more contrast between lights

[1] For further data relative to the eye see papers by Dr. H. H. Turner, p. 79, and by Dr. N. M. Black, p. 425, vol. IX, TRANS. I. E. S.

and shadows in the photographic image than actually exists to the eye. Also the red end of the spectrum (according to the retinal image) appears to be the brightest, while in the photographic image the blue end appears to be the brightest. It is a well-known fact that when one wears dark blue or green, the studio camera reproduces them as light shades, whereas dark red or yellow appear as dark shades.

In order to correct these difficulties, it is therefore necessary to find some way of making the photographic emulsion; first, insensitive to ultra-violet; second, less sensitive to violet and blue; third, more sensitive to yellow and red.

Considered additively, the color yellow is a combination of red and green; so that a transparent object which appears yellow by transmitted light is one which absorbs violet and blue and transmits red and green. It is obvious, therefore, that the first two of the above-mentioned requirements may be satisfied if the ultra-violet be eliminated and the violet and blue subdued by interposing between the emulsion and object a yellow transparent filter of just the right hue to transmit the amount of blue necessary to effect a balance between its visual and photographic images.

The sensitiveness of the emulsion to yellow and red can be increased by utilizing the comparatively recent discovery that certain dyes when mixed with the emulsion render it more sensitive to the yellow portion of the spectrum. Others increase the sensitiveness into the red end.

Plates or films rendered sensitive to the yellow as well as to the blue and green portions of the spectrum are termed isochromatic or orthochromatic, while those which are sensitive throughout the entire spectrum are termed panchromatic.

Curiously enough, a panchromatic plate is least sensitive to that portion of the spectrum to which the eye is most sensitive, that is, the yellow-green, so that unlike ordinary plates which must be developed in a light of low luminosity to the eye (red), a yellow-green, dark-room light of good luminosity may be used.

It may be interesting to now briefly review some of the more important steps in the development of our subject. The earliest

experiments were conducted by Becquerel, Seebeck and others, commencing about 1810, and were confined to what are termed direct methods of producing photographs in color. The indirect methods had not then been thought of. By direct methods I mean those in which the light sensitive surface directly takes on the color of the light to which it is exposed. The indirect methods contemplate the production of several pictures which are independently colored and then superposed to give the final results.

These early experimenters utilized certain light sensitive silver salts which when exposed to colored light took on in a greater or lesser degree the colors falling upon them; this appearance, however, was not permanent, as the colors soon faded. In 1868 this phenomenon was explained for the first time by Zenker on the theory of the production of stationary light waves in the silver emulsion by interference of the impinging and reflected light rays.

About the same time it was discovered that many pigment colors were sensitive to light, becoming bleached through its action. Wiener, in investigating this phenomenon, determined that a light sensitive substance can be altered only by those colored rays which the substance absorbs; hence red light would have no effect on red, but would bleach out blue and green; green no effect on green, but would bleach out blue and red, etc.

If, therefore, a light sensitive surface made up of fugitive dyes of the three primary colors is prepared and exposed under a colored transparency, a color print in duplicate of the transparency will be obtained. This theory forms the basis of some of the more important development work now going forward, and it is very probable that it will lead to a satisfactory solution of the problem so far as paper prints are concerned. Thus far, however, the 'utocolor' paper invented by Dr. Smith is the only process based on this phenomenon which is commercially available.

In the course of his experiments Dr. Smith found that certain dyes had a tendency to wander from a coating of one medium to another, as for example, from gelatine to collodion and vice versa, due to the affinity which acid dyes exhibit towards gelatin

and basic dyes exhibit towards collodion. He was able thereby to greatly simplify the selective coloring of his emulsion layers.

Utocolor paper involves, however, inherent limitations as to time of printing, brilliance of color, etc., which makes it still somewhat unsatisfactory.

In 1891 Professor Lippman confirmed Zenker's theory, by evolving a direct process producing permanent color transparencies and due entirely to interference phenomena. The Lippman process requires an ordinary photographic plate in a special plate holder arranged to hold mercury. The plate is placed in the holder with its glass side facing outward and the mercury poured in behind to form a mirror backing for the emulsion. The plate holder is of course so designed as to prevent any leakage of the mercury. On exposure in the camera the impinging light rays strike the glass plate first, then pass through the emulsion and finally arrive at the mercury mirror surface, being then reflected back through the emulsion retarded in phase angle so that interference with following impinging rays takes place. This interference creates stationary light planes of maximum and minimum intensity throughout the emulsion and parallel to the emulsion surface, and of course affects the silver in the emulsion in maximum amount at planes of maximum intensity, and in minimum amount at planes of minimum intensity. After development these planes of reduced silver operate selectively on incident white light so that when viewed along the angle of reflected rays the original picture in its natural colors becomes visible. This process, however, while capable of very beautiful results, is of scientific interest mainly and very few workers have been able to produce satisfactory plates with it.

It is now in order to mention the work done along lines which form the basis of our successful present-day processes. In 1868 Louis Ducos du Hauron, utilizing the principle laid down by Clerk Maxwell, who in 1861 analyzed all color combinations into a mixture of three primary colors, discovered the 'Three-Color Filter Process.' This was an indirect additive process and was independently discovered by two other investigators, Charles Cros and Frederick Ives. It consisted in taking three consecutive negatives of the colored object to be photographed, each

taken through a differently colored filter so as to selectively separate on each of the three negatives a primary color component of the original object. For example, one negative would be taken through a red filter which would allow only the red rays from the object to pass through and affect its negative. The second negative would be taken through a green filter, allowing only the green rays to affect its negative. The third negative would be taken through a blue filter, allowing only the blue rays to affect its negative.

Lantern slide positives of these three negatives would then be made and by means of a triple projection lantern the three images from the three slides would be superposed upon each other on the screen, after interposing between each positive and the screen its primary color filters as used in making the corresponding negatives. Each of these three superposed images would have therefore its own primary coloring and they would resolve into a combination image revealing the object in its original colors.

Ives in 1888 showed that the taking filters must collectively transmit all the rays of the spectrum of white light, while the viewing or reproducing filters need transmit only narrow bands of the spectrum, representing the three primary colors. Ives also devised the viewing apparatus known as the 'Kromskop,' which obviated the use of a projecting lantern, and by means of which the images of the three positives are optically combined to give a single colored image at the eye.

In addition to this additive method of reproducing the original object by means of superposed colored light images, it was shown that the reproduction could be made indirectly and subtractively by superposing prints from the three negatives upon each other. These prints must be very thin and the medium holding the image must be very transparent. They must also be individually dyed to their proper color before superposing. Further, they must not be dyed with a color the same as that of the corresponding taking filter, as in the additive process just referred to, but must be dyed with the corresponding complementary colors. For example, the positive printed from the red filter negative is colored with a blue-green (cyan blue) dye; that from the green filter negative with a blue-red (magenta) dye, and that from the blue filter with a red-green (yellow) dye.

The reason for this will be evident if we consider that here we are not dealing with overlapping lights, but with overlapping opacities in which each overlapping opacity or print absorbs part of the light transmitted by the other. To make this still clearer, consider an actual case, the reproduction say of a blue blotter. One would first take three negatives, red filter, green filter and blue filter. The red and green filters absorbing all blue rays would not show any image on their negatives, coming out transparent, while on the blue filter negative would be the well defined image of the blotter, more or less opaque in the high lights and transparent in the shadows.

On making positives for the additive or projection process, the red and green filter positives would come out opaque and the blue filter positive would show the image of the blotter transparent in the high lights and more or less opaque in the shadows.

On projecting the three positives through their respective reproduction filters, red, green and blue, no light would pass through the opaque red and green positives, while the blue positive would project a blue image of the blotter on the screen, brightly blue in the high lights, darkly blue in the shadows, thereby producing the desired effect.

With the subtractive process, as in the additive process, the positives from the red and green filter negatives would be opaque and from the blue filter negative would show a well defined image transparent in the high lights; more or less opaque in the shadows.

On dyeing, the prints from the red and green filter negatives, would take up great quantities of their respective cyan blue and magenta dyes. The prints from the blue filter negative would take up a small amount of yellow dye in the high lights and more of it in the shadows.

When superposed therefore, and examined by ordinary white light, the overlapping cyan blue and magenta dyed prints would absorb the red and green, but not the blue components of the white light; the light parts of the yellow dyed print would absorb the blue falling upon it only slightly, giving a fairly bright blue reflection for the high lights, while the dark parts would absorb

a greater proportion of the blue, giving a dark blue for the shadows, thus again giving a correct image of the blotter.

This subtractive method forms the basis of all modern color process printing and the commercially available photographic print color processes as follows: Sanger-Shepherd, Ives, three-color carbon, three-color ozobrome, raydex, pinatype, polychromide, etc.

Space will not permit of a detailed explanation of any of these processes, but all may be found described in greater or less detail in the references to the literature appended hereto.

Next come the single plate color processes, which have contributed largely toward making color photography commercially successful. In 1869 Louis Ducos du Hauron conceived the idea of combining the three taking filters of the three-color filter process into a single tri-color filter. He constructed the filter by ruling fine lines of the three primary colors, red, green and blue, on a transparent medium, coated on a glass plate, the lines being parallel, adjacent and arranged in the same consecutive alternating order of coloring all over the plate. An ordinary photographic plate would be exposed in the camera with its emulsion in contact with the tri-color filter plate, the latter being on the side nearest the lens, so that the light rays would have to pass first through the filter before reaching the emulsion on the photographic plate.

The theory of this process contemplates selective action by each filter line upon the line of light passing through it, with consequent selective action upon the emulsion behind each line. Thus the red parts of the image would only affect the emulsion behind the red lines on the filter; the green parts only that behind the green lines and the blue only that behind the blue lines on the filter.

After exposure the plate is developed and a positive made in the usual way. The positive and the tri-color filter would then be placed together again, care being taken to align the two so that the image lines on the positive corresponding to the red, green and blue filter lines on the negative were directly in contact with corresponding red, green and blue lines on the tri-color filter.

On looking through the combined positive and filter, or on projection upon a screen, the picture would appear in its natural colors.

The fineness of the lines on the filter and therefore in the image on the positive, is so regulated as to make them individually indistinguishable, advantage being taken of the limitation of the eye in observing minute objects, as previously pointed out. This not only merges the lines together to present a solid image, but also brings about the resultant color combinations of the primary colors necessary to bring out all the various shades of color in the object.

Du Hauron's process was not capable of commercial development, due to the lack at this period of a satisfactory 'panchromatic' plate, and also due to the mechanical difficulty of ruling up the filter plates.

During this same year, 1869, Du Hauron conceived the idea of coating the emulsion directly over the tri-color filter instead of using a separate plate, and after exposure and development, chemically reversing the negative to form a positive image. In order to overcome the mechanical difficulties involved in a ruled filter, he conceived the idea of dyeing minute particles of a transparent substance with the three primary colors, mixing them together intimately and spreading them in a single layer over the glass plate to form the tri-color filter, the emulsion then being coated upon it, as previously referred to.

It is obvious that this would give a heterogeneous pattern of color instead of a recurring regular pattern as in the ruled line filter. It is further obvious that only with a combined emulsion coating and filter as just described can such a filter be used, for it would be next to impossible to align such an irregular pattern with its corresponding positive as would be necessary where the panchromatic emulsion was on a separate plate. It follows, therefore, that a regular geometric arrangement of colors must be used in a tri-color filter, or screen (as we will now call it), where the separate single plate process is involved, and either a geometric or irregular arrangement may be used with the combined single plate process.

Lack of a satisfactory panchromatic emulsion and other diffi-

culties prevented Du Hauron from achieving commercial success with the combined single plate process.

During the next forty years various experimenters worked to produce a commercially successful single plate process, notably Joly, McDonough, Powrie and Miss Warner. Their work was all very ingenious and very beautiful results were obtained, especially with the Warner-Powrie process, but commercially they never met with satisfactory development.

In 1904 the Lumieres of Lyons, France, patented the well-known 'autochrome' process, which represents the successful development of a combined irregular single plate process, along the lines laid down by Du Hauron. This process leaves nothing to be desired so far as the production of transparencies, quickly, easily and with truthful color rendition is concerned. It is capable of producing very beautiful lantern slides upon the exercise of somewhat greater care and experience.

I will quote from a description of the process by Auguste and Louis Lumiere in a recent issue of *American Photography*:

Grains of potato starch are separated by special machinery so as to reject all smaller than 10 or larger than 15 thousandths of a millimeter in diameter (0.0004 in. to 0.0006 in.). The grains once selected are divided into three lots, which are colored orange, green and violet by means of appropriate dyes. The colored grains are then mixed in such proportions as to give a mixture having no dominant color. The extremely intimate and homogeneous mixture of the three colored powders is then coated regularly, by means of special machinery, on plates of glass previously coated with a sticky varnish. After this operation, it is necessary to fill the spaces between the grains, which is done by another machine which coats the plates with an extremely fine carbon dust. This dust is retained between the grains by the sticky varnish. The plate, thus prepared, is rolled to flatten out the starch grains and produce a three-color mosaic. The plate, though covered with microscopic elements stained intense orange, green and violet, seems to present no coloration, because the orange, green and violet rays which traverse it combine to form white light.

How can this mosaic of colored screens give birth to colored images? The mechanism of the genesis of colors is extremely simple. It is by subtraction, by the partial or total obscuration of such or such a colored grain, that the formation of the most diverse colors can take place. Let us suppose that we obscure the green and the violet grains; the orange grains alone remain, and the plate, viewed with the naked eye, presents an orange coloration. If we darken a single color, the hue of the plate

is the resultant of light which comes through the other two. If the blocking out of a given grain, instead of being total, is partial, the resulting color can take the most varied tints.

The sensitive emulsion is coated over the mosaic screen and automatically registers and reproduces the colors of the object. Exposure is made through the glass side of the plate so that the light traverses the colored grains and impresses the silver in proportion to the amount of the three primary colors present. On treating the plate with a developer, metallic silver is deposited over every grain through which light has passed in proportion to the amount of light action. Thus, if the object is green, every green grain will be covered with silver, and if the process were stopped at this stage the image would be red, because the image would be formed by the unaltered orange and violet grains. This image is the complement of that which it is desired to obtain.

But if we dissolve, by means of appropriate chemicals, the silver reduced by the first development, the green grains would be freed and rendered visible, only we should still have the unaltered silver bromide covering the orange and violet grains.

Let us proceed, then, in broad daylight to a second development. This unaltered bromide will be affected by light in its turn and blackened by the developer. Consequently the orange and violet grains will be masked in their turn and the green grains alone remain visible. We have thus reproduced the green image after having passed through a complementary red image.

This explanation can be repeated for every other color, and one sees that all colors are formed by subtraction by eliminating, partly or totally, from the orange-green-violet layer, the elements of the colors complementary to the color which is to be obtained. This elimination, this selection, is effected automatically by the colored rays themselves coming from the object photographed.

In practise the manipulation of "Autochromes" is very simple. A special yellow-orange screen is placed on the lens. The plate, in contact with a sheet of black cardboard to prevent scratching of the sensitive coating, is loaded into the plate holder with the glass side towards the lens. The same developer (metoquinone with ammonia) is employed for both the first and second development. Reversal takes place in a bath of potassium permanganate acidified with sulphuric acid, and all processes after the flowing of this solution over the plate take place in broad daylight. Within 20 minutes of beginning work, a finished positive in colors may be produced, and as soon as it is dried it may be varnished and bound up like a lantern slide.

It should be noted that in this process as in all other single plate processes a compensating yellow or orange filter must be used on the lens to eliminate ultra-violet and cut down the violet and blue rays, as previously explained. It should also be noted

that due to the action of the yellow filter and tri-color screen in cutting down the actinic value of the light, a great increase of exposure time over the ordinary plate is necessary, varying from 25 to 100 times that required for the latter.

Following quickly upon the autochrome came the Thames, omnicolore, and aurora, or Dufay dioptichrome single plate processes, each representing ingenious attempts to solve the problem in a slightly different way. All have achieved fair commercial success, but cannot be said to equal that of the autochrome from the standpoint of manipulation or results.

In 1913 the Paget single plate process was brought out, representing a development of the separate geometric screen method as laid down by Du Hauron. It involves a tri-color screen printed in checkerboard pattern upon the screen plate, the squares on the checkerboard being about 1/500 in. on a side. A separate taking and viewing screen, special panchromatic negative plate, special orange filter and special positive plate are necessary. Later the company succeeded in combining the viewing screen and the positive into a single plate. This process is capable of very beautiful results, is especially adapted for latern slides and threatens to compete seriously in public favor with the autochrome process, having an advantage in its possibilities of duplication from the original negative, not possessed by the latter.

As to the future one may say it is very hopeful. The Lumieres and others are diligently working to perfect the bleach-out print process. The Eastman Company has recently induced the well-known English authority on this subject, Dr. C. E. Kenneth Mees, to join its staff at Rochester, and it is understood that he is actively directing the work along this line. It is the hope of all interested in this subject that the near future may have in store for us the perfected photographic print in natural colors.

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TESTS OF SOME POSSIBLE REFLECTING POWER STANDARDS.*

BY P. G. NUTTING, L. A. JONES AND F. A. ELLIOTT.

Synopsis: This paper deals with determinations of the absolute reflecting power of various reproducible, diffusely reflecting surfaces with which the reflecting powers of other surfaces may readily be compared.

The reflecting powers of two diffusely reflecting surfaces may readily be compared by a simple determination of their relative brightness under the same illumination. To determine the absolute reflecting power of any one surface is much more difficult, hence it is advantageous to have standards of known reflecting power with which the reflecting powers of other surfaces may be compared and the readings of reflecting power instruments checked.

We have made an extended investigation of the surfaces of various substances promising usefulness as reflection standards, chiefly colorless fine crystalline oxides and salts, bearing in mind reproducibility of surface, the effect of impurities, systematic errors of determination and percentage of specular reflection. The investigation was begun at the Bureau of Standards two years ago by Jones and Nutting. During the past year observations were made on the same substances at the Research Laboratory of the Eastman Kodak Company with a different instrument by a different observer (Elliott), thus providing excellent data on reproducibility and precision of measurement.

Reflecting powers were determined with Nutting's absolute reflectometer, described and exhibited at the Niagara Falls convention of this Society in 1912. This instrument determines in effect the relative brightness of the opposed surfaces of two infinite parallel planes, one of which receives all its illumination from the other. The reflecting power of the surface illuminated is its brightness relative to that of the surface illuminating it. A good approximation to infinite planes is obtained by placing

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between the planes a cylindrical ring 6 inches (15.24 cm.) in diameter and 1 inch (2.54 cm.) wide, of polished nickel. This returns the light that would otherwise escape between the planes, producing an edge correction. Relative brightness is measured at the center of the ring with an ordinary Martens photometer inserted in one side of the ring. Details of the construction, theory and operation of the instrument are given in the article describing it published in the TRANSACTIONS of this Society[1] and in the *Journal of the Washington Academy* for 1912, page 505.

The uncertainty in a determination of reflecting power with this instrument is of the order of half a per cent. The following set of eight readings on magnesium carbonate surfaced with a glass disk are a fair example of the agreement in readings taken at different times by the same observer with the same instrument.

REFLECTING POWER OF MAGNESIUM CARBONATE POWDER SURFACED WITH GLASS.

	R_1	R_2	R	Deviation
	91.2	85.9	88.55	—0.92
	92.4	85.2	88.80	—0.67
	91.0	86.5	88.75	—0.72
	93.3	88.4	90.85	1.38
	92.4	87.0	89.70	0.23
	92.5	87.6	90.05	0.58
	92.2	86.3	89.25	—0.22
	92.7	86.9	89.80	0.33
Mean	92.2	86.6	89.5	0.6

The measured reflecting powers R_1 and R_2 are for polarization in and perpendicular to the plane of observation taken with the photometer direct and reversed. The illuminating surface is a plate of solid opal glass, 3 mm. thick, rough ground on both sides. Determinations of the percentage of specular reflection from such surfaces range from 3.0 to 3.4 per cent., hence in determinations with the reflectometer, the percentage specular reflection of the surface whose reflecting power is being measured is roughly 3 per cent. less than the difference R_1—R_2.

The magnitude of the error due to the illuminated and illuminating surfaces not being parallel is indicated by the following observations on boric acid powder, the (glass) pressed surfaces

[1] TRANS. I. E. S., vol. VII, p. 412.

being inclined 15 deg. toward and away from the photometric axis.

BORIC ACID POWDER.

	R_1	R_2	R
15° from axis	86.3	80.6	83.4
15° toward axis	89.7	84.6	87.1
½ difference	1.7	2.0	1.9

The error due to slight deviations from parallelism (less than 3 deg., say) is therefore quite negligible.

The effect of the condition of the surface on the reflecting power is shown in the following data. The surface designated by "smooth" was prepared by pressing with a glass disk, "mat" with a disk faced with medium grained sandpaper, "brushed" by brushing slightly with a soft brush, "rough" by merely shaking the sifted powder until level.

	Smooth	Mat	Brushed	Rough
Calcium carbonate, mean R	87.9	87.5	86.1	83.4
Calcium, per cent. specular	3.2	2.9	2.7	2.3
Alumina, mean R	87.3	85.8	81.9	—
Alumina, per cent. specular	3.2	2.5	1.3	—
Magnesium carbonate, mean R	89.4	86.6	—	—
Magnesium, per cent. specular	2.6	1.4	R	P
Magnesium, solid block scraped flat	—	—	88.0	1.7
Magnesium scrapings from block, smooth	—	—	87.0	2.7

The effect of size of grain on reflecting power was determined on sugar, common salt, glass and snow.

	R_1	R_2	R	P
Sugar—				
Cubes 1/4 to 1/8 inch (6.35 to 3.17 mm.)	72.7	67.0	69.8	2.7
Cubes 1/8 to 1/16 inch (3.17 to 1.59 mm.)	80.1	72.4	76.2	4.7
Cubes about 1/32 inch (0.8 mm.)	86.1	79.2	82.6	3.9
Very finely powdered	91.8	83.9	87.8	4.9
Glass—				
Beads 3/32 inch diameter (2.38 mm.)	36.7	36.1	36.4	2.4
Powdered (0.2 mm.)	86.7	81.5	84.1	2.2
Salt—				
Crystals 1/4 to 1/8 inch (6.35 to 3.17 mm)	76.3	71.1	73.7	2.2
Crushed to 20 to 80 mesh	82.5	76.1	79.3	3.4
Snow—				
Fine, dry, drifted	86.7	82.8	84.7	0.9
Natural surface, fresh	76.6	63.8	70.2	9.8
Old, beady	69.8	65.8	67.8	1.0

The following table contains the data on substances investigated at both Washington and Rochester. The materials are from different sources and both the instruments and observers are different in the two cases:

		R	R_1	R_2	P
Boric acid powder (commercial)	W	85.9	88.7	83.2	2.5
Boric acid powder	R	86.2	89.3	83.1	3.2
Aluminum oxide, dry	W	87.9	91.0	84.9	3.1
Aluminum oxide	R	85.7	88.7	82.7	4.0
Magnesium carbonate block	W	88.0	90.4	85.7	1.7
Magnesium carbonate	R	87.9	91.2	84.7	3.5

To obtain consistent results with crystalline substances these must be extremely finely powdered. If they contain water of crystallization it is in some cases best to dessicate and work with the water free form. We found for example for magnesium oxide heated to a high temperature in a vacuum electric furnace the highest reflecting power of any substance investigated, namely 88.1. On exposure to the air for a day this fell to 86.4 and finally to 85.3, the value given by the chemically pure commercial article.

REFLECTING POWER OF VARIOUS SUBSTANCES.

		R	R_1	R_2	P
Aluminum oxide	W	87.3	90.4	84.2	3.2
Aluminum oxide	R	87.4	90.7	83.1	4.6
Barium sulphate	R	*85.4	89.7	81.1	5.6
Borax	R	85.2	88.9	81.6	4.3
Boric acid (A. D. S.)	W	85.9	88.7	83.2	2.5
Boric acid	R	*86.2	89.3	83.1	3.2
Calcium carbonate	W	87.9	91.0	84.9	3.1
Calcium carbonate	R	85.7	88.7	82.7	4.0
Citric acid	R	84.8	88.1	81.5	3.6
Magnesium carbonate	W	89.4	92.2	86.6	2.6
Magnesium carbonate block, commercial	W	*88.0	90.4	85.7	1.7
Magnesium carbonate block, commercial	R	87.9	91.2	84.7	3.5
Magnesium oxide, dry	W	88.1	90.5	85.7	1.8
Magnesium oxide, commercial	W	*84.9	87.8	82.1	2.7
Magnesium oxide, commercial	R	85.3	87.9	82.8	2.1
Rochelle salt	R	82.2	85.1	79.3	2.8
Salicylic acid	R	84.8	88.5	81.1	4.4
Sodium carbonate	R	85.7	89.6	81.8	4.8
Sodium chloride	R	81.9	84.7	78.1	3.6
Sodium sulphite	R	*81.2	84.6	77.9	3.7
Starch	R	*83.4	86.5	80.3	3.2
Tartaric acid	R	83.0	88.0	79.1	5.9

The preceding list of the reflecting powers determined in this investigation. The surfaces were prepared by pressing with a glass disk. Those designated by (W) were determined in Washington in 1912, those by (R) in Rochester in 1914. Values designated by an asterisk are considered sufficiently reproducible to serve as reflection standards. The particles of all crystalline substances were of microscopic dimensions.

AIR SHAFT ILLUMINATION AS STUDIED BY MODELS.*

BY CLAYTON H. SHARP.

Synopsis: This paper presents photometric data, obtained from two miniature ideal air shafts, indicating the variation of illumination with variations in the reflecting power of the surfaces of the shafts. Reflection coefficients for several painted surfaces are given.

In spite of the importance of open shafts in the illumination of interiors, there seems to be an utter lack of data regarding the amount of light which may be received by the windows on the different stories in such a shaft. This amount of light depends upon the brightness and exposed area of the sky which shines directly on the window and also upon the reflecting power of the interior of the shaft. If the shaft has one or more sides open, the conditions are modified once more. The amount of direct skylight which will fall upon a window depends upon the solid angle which the sky subtends at that window. This depends again upon the dimensions of the shaft and upon the distance which the window is from the top of the shaft. The reflecting power of the interior depends upon the coefficient of reflection of the material of the shaft or of the paint with which it is covered, and upon the number and area of the windows in the shaft, which for practical purposes may be considered as black regions having no reflecting power. The flux of light which is admitted by a window may be taken as equal to the illumination on the window multiplied by its area; that is, the foot-candles times the number of square feet. It is upon this flux of light that the illumination produced in a room depends.

The purpose of this paper is to present some data bearing on

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

two ideal shafts and to show the variation of the illumination with variations in the reflecting power of the interior of the shafts. It is evident that these ideal shafts can not correspond to any actual case and that therefore the data obtained cannot be used directly in illumination calculations, but it is hoped that they may at least serve as a guide to the order of magnitude to be expected and that at any rate the experimental method used may prove useful in the approximate practical prediction of the performance of light shafts in buildings which are in process of design.

The assumption may be made that the performance of light shafts is independent of their actual dimensions and dependent only upon their relative dimensions. Therefore a small light shaft may be constructed of the same shape and the same relative size as the shaft which is designed and from measurements made on the model shaft the performance of the actual shaft may with some certainty be predicted. In the experiments here recorded a light shaft was constructed of wood, interior dimensions 50 x 50 cm. (19½ by 19½ in.), and a total length of 4 meters (14 ft.). One end of this shaft was covered by a sheet of plain milk glass. Behind this was placed a box painted white in the interior, containing five tungsten lamps, four of them being of the 150-watt size and one of them of the 250-watt size. By these lamps the milk glass was very brightly and very uniformly illuminated. It was assumed that the plain glass so illuminated was for practical purposes a sufficiently good imitation of the open sky above a shaft. Small openings were made in the shaft at distances from the glass equal to one half of the width of the side, namely 25 cm. (9½ in.). Therefore in going two windows away from the glass, a distance equal to the width of the side of the shaft was covered. That is, this half width was taken as the unit of measure of distance down the shaft. In making the measurements the tube carrying the test-plate of a small photometer was inserted in the window or opening in such a way that the plane of the test plate coincided with that of the interior of the shaft and the illumination falling on the test plate was measured in the usual way. In some tests the base of the shaft was painted the same color as the interior; in most of them it was black, this

being assumed to be a more general condition. The interior was painted successively with ordinary white paint; white enamel paint, quite glossy; mat white cold water paint; a very light yellow calcimine; a kind of a chocolate color calcimine; a brick red, mat surface calcimine; dead black paint.

All of the above mentioned measurements were repeated with the shaft reduced in size one half by moving one side over, so that its dimensions became 25 x 50 cm. (9½ x 19½ in.). In the case of the latter shaft it was found that measurements of illumination showed practically the same result whether they were taken in the middle of the 25 cm. side or in the middle of the 50 cm. side. Therefore for convenience all measurements were made in the middle of the 25 cm. side. As a control the brightness of the milk glass as seen from the shaft was measured in connection with each experiment. This was done by inserting a small 45° mirror in the shaft and observing the surface of the milk glass through it, the test-plate of the photometer being removed. Subsequently all measurements were reduced to the same value of brightness as that of the milk glass, namely 0.210 candle-power per square inch (0.0326 candle-power per sq. cm.).

It should be emphasized that no extraordinary care was taken to secure a high degree of accuracy in the measurements. Inasmuch as their application can be approximate only, it did not seem worth while. Moreover the range of illumination values which had to be covered was very great. Measurements taken at the top of the shaft were very easily thrown into considerable error by very small variations in the adjustment of the test plate and near the bottom of the shaft the illumination intensities were in most cases so very low that no high accuracy could be hoped for. In these facts is to be found an explanation for the inconsistencies which are apparent in the results, which inconsistencies, however, do not appear to lessen the value of the results for practical purposes.

Inasmuch as the window illuminations in the shaft are produced not only by the sky directly but also in a large measure by reflection from the sides of the shaft, the mathematical relations involved in this study are very complicated and hence no mathematical study has been attempted. It will be found, however,

that the variation of illumination is not a simple function of the distance, but quite a complicated one, so that a mathematical expression for it would be of doubtful value.

The results are presented in the form of curves which are for the most part self-explanatory. The different curves refer to

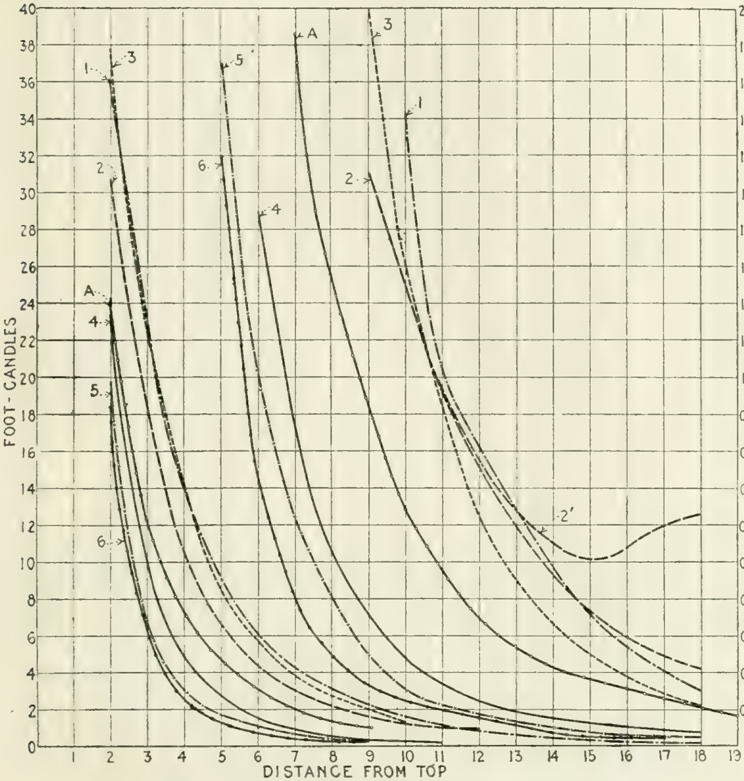


Fig. 1.—Square shaft. Illumination values on side.

the aforementioned paints used in the interior, the designations being as follows:

A. White paint, black base.
1. Mat white, black base.
2. Enamel white, black base.
2′. Enamel white, white base.
3. Light yellow, black base.
4. Chocolate color, black base.
5. Brick red, black base.
6. Dead black.

Fig. 1 gives illumination values found in the shaft of square

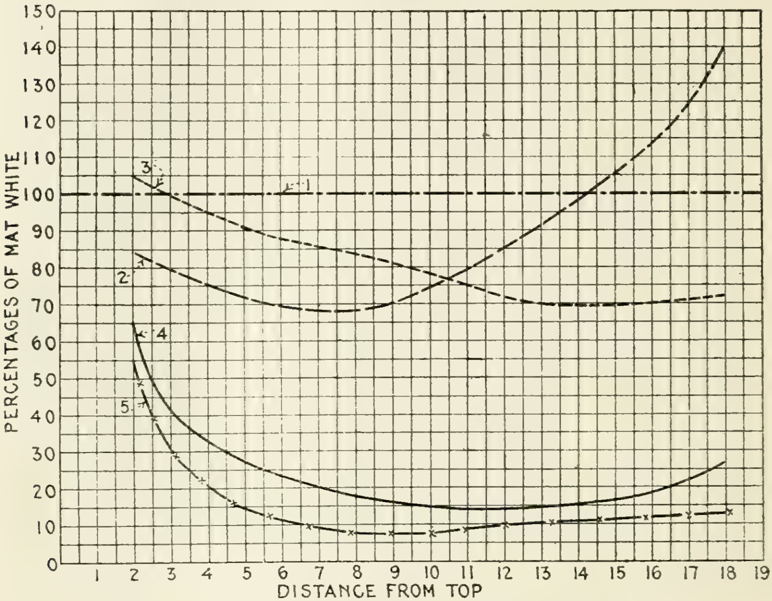


Fig. 2.—Square shaft. Illumination values relative to mat white.

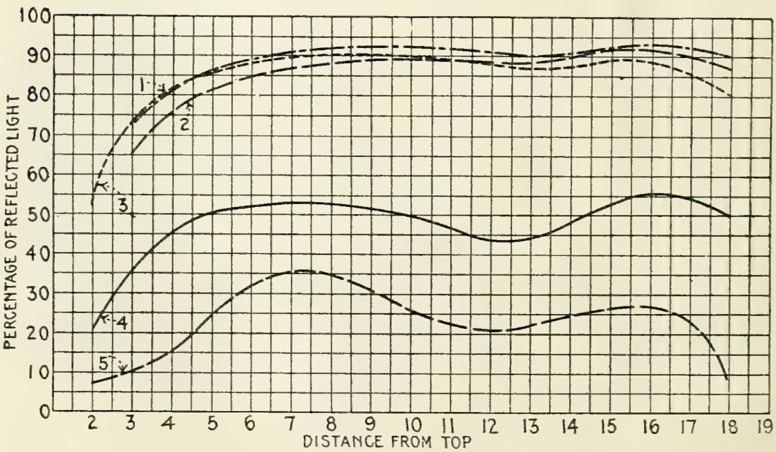


Fig. 3.—Square shaft. Percentages of total light due to reflection.

section. It will be noticed that two scales of ordinates are used in order to make the entire course of the curves readable.

Fig. 2 shows the percentages of light received by the windows

in the square shaft with the various paints in terms of that received when the shaft had the mat white surface.

Fig. 5 shows the percentages of reflected light in each case. These percentages are obtained by subtracting from the observed illuminations the illumination values found when the interior of the shaft was painted black, the reflection of the dead black

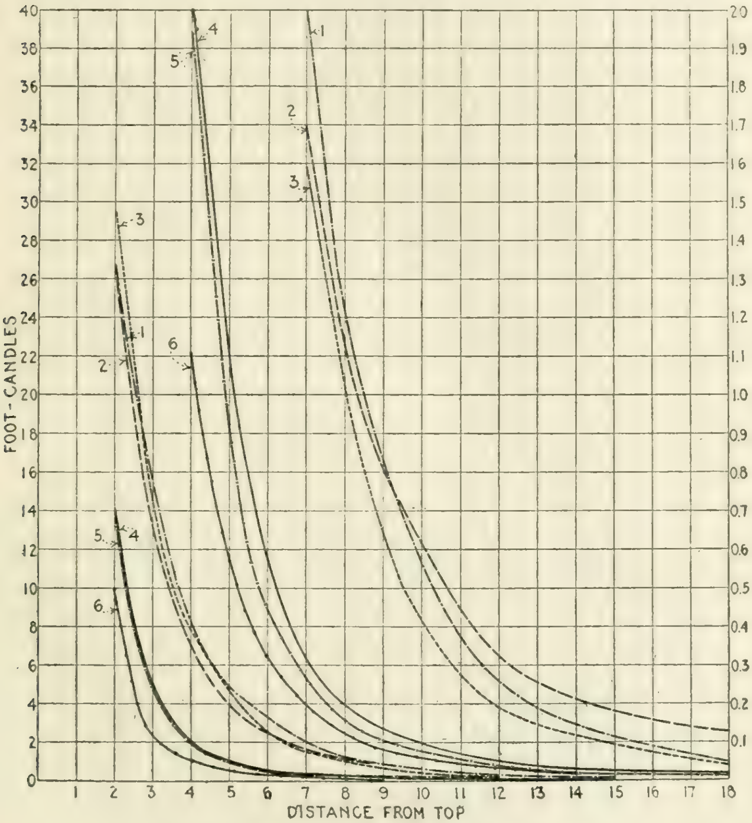


Fig. 4.—Oblong shaft. Illumination values on side.

surface being considered for all practical purposes equal to zero.

Figs. 4, 5 and 6 correspond to Figs. 1, 2 and 3 and refer to the shaft of oblong section.

These points of interest may be noticed.

1. The effect of using a glossy white surface instead of a mat white surface is to increase the illumination near the base of the

shaft as compared with that higher up. Hence for deep shafts at

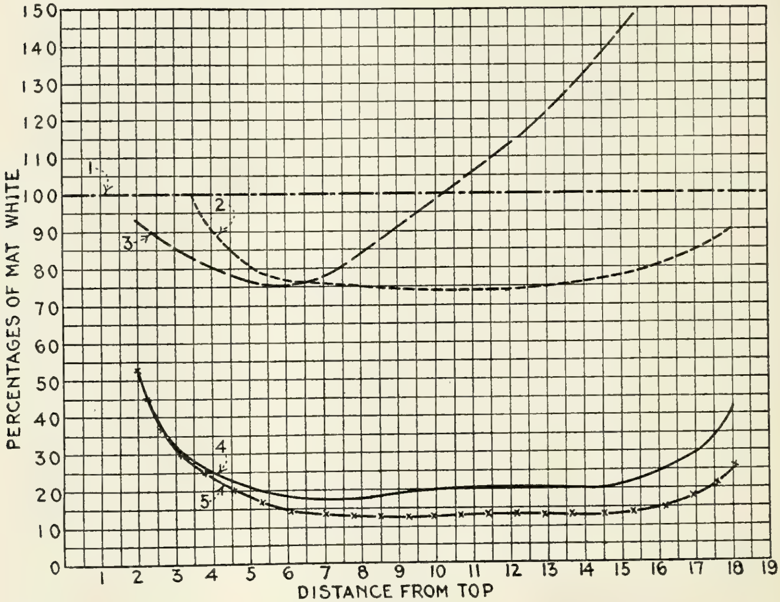


Fig. 5.—Oblong shaft. Illumination values relative to mat white.

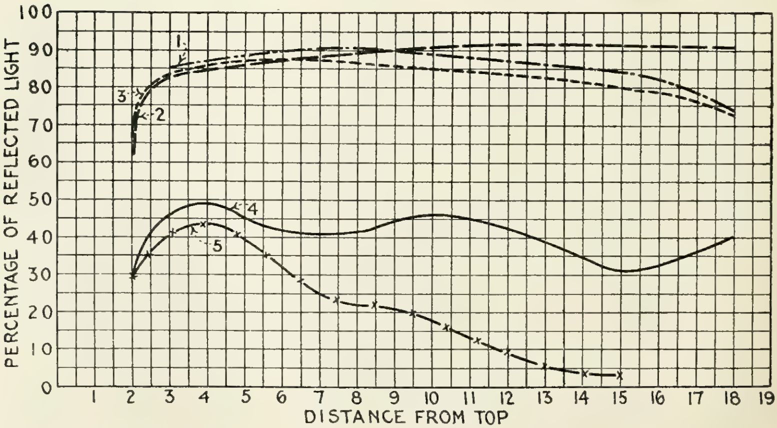


Fig. 6.—Oblong shaft. Percentages of total light due to reflection.

any rate, a glossy surface is advisable. This relation is brought out in a striking way in Figs. 2 and 5.

2. The great gain in illumination due to having a color of high

reflecting power is quite evident. In the following table are given values for the coefficient of diffuse reflection of the different paints used as measured directly by a photometer and also the average values of the percentages of reflected light as shown in Figs. 3 and 6. In computing these averages the values at window No. 2 are omitted as being so close to the sky that the reflection plays a relatively small part. It will be noted that the

Paint	Coefficient of diffuse reflection	Percentage of reflected light	
		Square shaft	Oblong shaft
Mat white	88.5%	89.3	86.7
Enamel white	—	86.6	88.6
Light yellow	86.7	86.4	83.6
Chocolate	40	41.5	41.5
Brick red	32	21.8	15.2
Black	0 (assumed)	—	—

percentages of reflected light are almost equal to the coefficients of diffuse reflection expressed in per cent. The one exception is in the case of the brick red shaft where, particularly with the narrow shaft, the values fell much below the directly measured value of the coefficient. This is a discrepancy which it has not been practicable to clear up. The concordance of the other results, however, points rather definitely to the important conclusion that the percentage of the light received by the windows due to reflection from the sides of the shaft is equal to the average coefficient of reflection of the interior surface of the shaft. This relation may be of considerable value in predicting daylight illumination in actual air shafts.

Certain measurements were made also with a black base inserted half way down the shaft. The only effect of this was to reduce somewhat the illumination values observed near this black base. Since in any practical case the base of a shaft is not black, but somewhat reflecting, there would probably be little error in using for a shorter shaft the values in the curves for the full length shaft as given above.

The foregoing work was done with the aid of the resources of the Electrical Testing Laboratories. Most of the photometric measurements were made by one of the regular, skilled photometer operators.

DISCUSSION.

Dr. A. S. McAllister: An examination of the test results recorded by Dr. Sharp discloses the fact that the incident normal illumination along the side of the air-shaft has a value inversely proportional to the cube of the distance down the shaft to the point of observation. Expressing the relation in numerical values it is to be noted that when the illumination measurement at each point down the shaft in foot-candles is multiplied by the cube of the distance to this point there is obtained a value which is roughly constant for all locations, the variation taking place in a somewhat irregular manner from 144 at 2 distance-units; reaching 160 at 5 units; decreasing to 116 at 9 units and increasing to 140 at 13 distance-units. At depths below 15 distance-units the readings are somewhat uncertain and can well be ignored for present purposes.

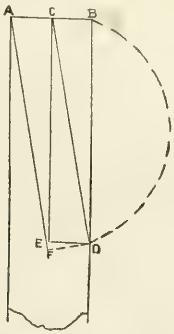
That the inverse-cube relation should hold to a first degree of approximation can easily be shown by means of the accompanying simple graphical diagram.

For sake of absolute simplicity assume initially that the shaft is circular rather than square or oblong in horizontal cross-section, and that the sides are painted black—that is, they have a 100 per cent. absorption coefficient.

Let β be the luminous flux density of the sky—either the actual value supplied by nature or that produced on the interior of the artificial sky shown at AB in the illustration. The luminous density output of the sky opening should be expressed in terms of the total number of lumens received by the shaft from the sky divided by the area of the sky opening. When the area is measured in square feet the density is expressed in lumens per square foot, or foot-candles. This method of expressing the output density is far preferable to, and much more significant than, that of stating it in terms of the "candle-power per square inch" which is usually referred to as the "brightness." When expressed in candle-power per square inch, the luminous output density can be converted to foot-candles by multiplying the "candle-power per square inch" values by $144\pi = 452$.

At any point F along the center of the shaft the (foot-candle) illumination on the horizontal plane will bear to that of the sky

at AB, β, the ratio of the square of AC to the square of AF, or will vary inversely with the square of the distance down the



shaft, the distance being expressed in terms of the radius of the source AC and measured along the diagonal AF.

By drawing through points F and B a circle having its center along the line CF, a point D is located along the side of the air-shaft at which the horizontal illumination is equal to that at F.

The vertical component of the illumination at point D, which is the final value desired, is equal to the horizontal component at D divided by the distance BD expressed in terms of the radius CB or AC.

The above-mentioned relations were fully set forth in a paper entitled "The Law of Conservation as Applied to Illumination Calculations," presented by the speaker at the Chicago convention of the Society in September, 1911, and need not here be enlarged upon.

From the above demonstration it will be seen that the illumination of the side of the air-shaft at D, β_D is equal to the illumination of the sky at AB divided by the numerical value

$$(AF \times AF \times BD) \div (AC)^3 \text{ or } \beta_D = \frac{\overline{AC}^3 \beta}{\overline{AF}^2 \overline{BD}}.$$

When the depth down the shaft is large compared with the radius of the sky opening, AF is practically equal to BD and it can be said that the illumination varies inversely as the cube of the depth, as stated above.

Although the conclusions just derived are applicable directly

only to shafts of circular section, yet the modifications required in applying them to oblong or square shafts can readily be made. Perhaps the most convenient method of solving the problem relating to a square shaft is to assume the substitution therefor of a circular shaft having an equal area of sky opening, that is, a circular shaft having a diameter 12.9 per cent. larger than the side of the square. For an oblong shaft opening there can be substituted an elliptical source having major and minor axes 12.9 per cent. larger than the sides and ends of the air-shaft.

In the case of the oblong shaft tested by Dr. Sharp the ellipse would have a major axis equal to the diameter of the original circular source and a minor axis of one-half this length. When viewed from any point down the center of the narrow side of the oblong shaft the ellipse would subtend a solid angle equal to one-half of the solid angle subtended by the circular source when viewed from a point equally distant down the center of one of the sides of the square shaft. Hence the luminous flux density at each point down the narrow side of the oblong shaft should be just one-half of the density at the corresponding point in the square shaft. This conclusion is substantiated by Dr. Sharp's test data.

Assume now that instead of being coated with paint having 100 per cent. absorption, the interior of the shaft is painted with a material having less than 100 per cent. absorption. Obviously a certain amount of the light entering the shaft from the sky will be reflected out into the sky again so that the total number of lumens absorbed by the walls and bottom of the shaft will be somewhat less than the value represented by the product of the area of the top of the shaft opening and the sky flux density in lumens per unit area. In the extreme case of 0.0 per cent. absorption—100 per cent. reflection—the illumination density along the whole interior of the shaft becomes equal to that of the sky and the amount of lumens reflected out into the sky through the opening is exactly equal to the amount received from the sky through the same opening. In any practical case, say with an absorption of 20 per cent., the amount of light reflected outward through the opening is very small and for present purposes can best be ignored.

Assume, therefore, that the number of lumens entering the shaft, and therefore the number of lumens absorbed by the walls and bottom of the shaft, is equal to the product of the area of the sky opening by the density in lumens per unit area of the opening. On account of the reflection and re-reflection between the walls and bottom, the incident flux density at each point along the shaft is increased to such an extent that the average density over the whole absorbing area become $100 \div 20 = 5$ times as great as the value received directly from the sky. That is to say, with an absorption coefficient of 20 per cent. the average flux density over the shaft sides and bottom is 5 times as great as is true with 100 per cent. absorption. Thus the average density is so increased that when multiplied by the absorption coefficient it equals the incident flux density received from the sky opening; or the portion of the light attributable to reflection bears to the total light received a ratio equal to the reflection coefficient, a fact to which Dr. Sharp has called attention.

In the discussion thus far, the actual distribution of the flux under various conditions of reflections has been ignored. The tests reported would indicate that with matt surfaces the final light flux distribution is practically identical with the distribution of flux received directly from the sky opening. Such a result is to be expected in view of the fact that each point along the shaft becomes a secondary light source excited "initially" by the flux from the sky and building up in flux in proportion to the amount it receives by reflection; this amount varies with the position of the point along the shaft, in a manner approximating closely the law of variation of the incident flux density, and hence the final density bears approximately a constant ratio to the initial incident density. Near the top of the shaft a considerable portion of the light produced at the "secondary" light sources is sent out into the sky and lost. The same condition exists at the lower end of the shaft, if open or if closed by a light-absorbing bottom. These conclusions are in exact accord with Dr. Sharp's results.

In studying the effect of using a glossy instead of a matt surface it is instructive to consider first what would be the result

if use were made of absolutely perfect mirrors for the sides. Evidently under this condition the effect would be identical with lowering the top of the shaft opening to the bottom of the mirrors. When the mirror has less than 100 per cent. reflection, the same general effect is produced but the light transferred to the lower end of the shaft is materially reduced by the absorption. In any practical case, a glossy surface acts as a combination of a diffusing surface and a mirror of appreciable absorption. It tends to transfer the flux from the top toward the bottom of the shaft, relatively increasing the illumination at the lower end of the shaft, a fact established by Dr. Sharp.

MR. L. B. MARKS: This paper is a most valuable contribution to the art, in that it takes up a problem that we meet with frequently in practise. I don't know whether the court house problem[1] could be solved by the mathematical method which Dr. McAllister has offered, but at the moment I don't see why it could not be. The problem is very much more difficult, I think, than this simple problem of the cylinder. In the case of the court house we have a large cylinder with a circular opening extending down to its base; inside of this opening is placed another cylinder of small diameter. Now, what we are concerned with is the illumination of the outer surface of the inner cylinder and the inner surface of the outer cylinder. As these two cylinders are crossed by numerous bridges of different shapes, you have a most intricate problem to solve, mathematically.

It would be very interesting indeed if Dr. McAllister, in carrying along the inquiry which he has directed to the shaft described in Dr. Sharp's paper, would go one step further and take the case of an annular court obstructed by bridges or other obstructions, and give us some simple mathematical method as apparently he has here, of computing the daylight illumination at the bottom of the annular court.

[1] Marks and Woodwell, Planning for Daylight and Sunlight in Buildings, TRANS. I. E. S., No. 7. Vol. IX.

A TRANSMISSION AND REFLECTION PHOTOMETER FOR SMALL AREAS.*

BY P. G. NUTTING AND L. A. JONES.

Synopsis: This paper describes a precision photometer for determining specular transmission or diffuse reflection in areas as small as 1 mm. square and with a special acular as small as 0.1 mm. square.

In many optical investigations it is desirable to measure the brightness of small areas—1 mm. square or less. The instrument here described was devised to measure the brightness of optical images, the local densities in photographic negatives, and the reflecting powers of different parts of photographic prints and other pictures. It has proved exceedingly convenient and precise, and so nearly all that may be hoped for in this type of photometer that a description may be of general interest.

The chief advantages secured in our instrument are the following:

1. The elimination of errors due to fluctuation in the comparison source by using the same source for comparison light and for the source of transmitted or reflected light.

2. The elimination of all corrections for shift of zero by providing easy means of balancing the two beams with an open system.

3. A direct view of the object sighted upon at all times during measurement. This is obtained by focusing an image of that object at the dividing line of the photometer cube.

4. An open linear scale, reading directly from zero to 100 per cent. provided by a rotating comparison beam and stationary sector. The photometer head used is, in fact, that of the Bechstein illuminometer. The ease and rapidity of setting provided by this form of variation of comparison beam are known to all who have used them.

A plan of the optical parts of the photometer as used for determining transmission, is shown in the accompanying figure.

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

Communication No. 15 from the Research Laboratory of the Eastman Kodak Co.

The source of light E is a condensed filament 100-watt tungsten lamp run on the lighting circuit. Light from this illuminates the comparison screen, C, of thin solid opal glass. This screen is viewed through the ocular O, the photometer cube, P, the rotating excentric lens, L_2, and stationary sector S. Light from E also passes to the photometer cube through the path ER_1R_2P. R_1 is a reflecting prism within a metal box mounted on a stand. The front face of this box is a plate of flashed opal glass, D, serving as a secondary source by diffusing the light. The plate whose transmission is to be determined is placed directly in front of this diffusing screen, thus eliminating errors due to scatter in the transmission measured. An image of the plate to

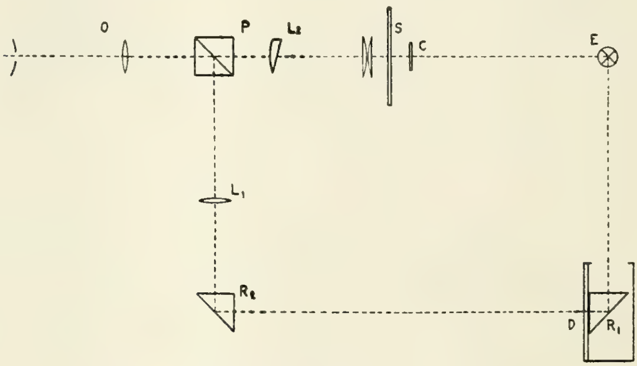


Fig. 1.—Plan of optical parts of the photometer.

be observed is thrown on the photometer cube, P, by means of the lens, L_1, and the reflecting prism, R_2. These latter pieces are mounted on an arm carried by the instrument itself, the lens L_1, being adjustable in position.

In use, the sector S, is first set to read 100 and the source, E, moved toward or away from C until a balance is secured without the plate to be measured. The instrument will then read correctly from zero to 100 per cent.

For determining reflecting powers, R_1 and D are not used and R_2 is rotated to face downward (instead of horizontally as shown). The surface upon which observations are to be taken is placed directly under it on the table and the L_1 focussed upon it. This surface is illuminated directly by the source E. Or-

dinarily, it is diffuse reflecting power that is desired, and the surface is placed horizontally,—specularly reflected light not entering the instrument.

The zero adjustments for measuring reflecting powers are as simple as for measuring transmissions. If only relative values are desired, as in measuring up a photographic print, clear paper is placed in the field, the sector set to read 100 per cent., and the source, E, adjusted to give a match at the cube.

If actual reflecting powers are desired, a mat surface, say a block of magnesium carbonate, whose reflecting power has been determined on an absolute reflectometer[1] is placed in position, the sector, S, set to read its absolute reflecting power and the source, E, adjusted as before. The instrument will then give directly the diffuse reflecting power of any other surface placed in the field.

If specular reflecting power is to be determined, total reflecting power is measured on the absolute instrument and diffuse reflecting power measured as just described.

The instrument, as a whole, is very easily, quickly, and permanently adjustable; readings may be taken with it as rapidly and accurately as with any kind of visual photometer, and we have not yet detected any systematic errors in its readings. For months it has been in constant use by a number of observers in the sensitometry of photographic plates and papers. With a magnifying ocular it may even be used as a microphotometer of low power.

[1] P. G. Nutting, *Jour. Wash. Acad. Sci.*, Dec. 19, 1912.

THE HIGH INTENSITY STREET LIGHTING OF EUROPEAN CITIES COMPARED WITH NEW YORK.*

BY C. F. LACOMBE.

Synopsis: The factors and considerations which influence the design of street lighting installations in large cities are here outlined. Differences between European and American practise are pointed out. Flame arc lighting and high pressure gas lighting are discussed briefly. The paper is concluded with descriptions of typical European installations; illustrations of these are included.

It is with great pleasure and gratification that I appear before you to-night, for it is impossible not to feel the honor of being the lecturer of the combined societies, for the year, twice in succession, and I would therefore express my sincere thanks for the privilege of again addressing you.

Those of you who heard my lecture[1] on the street lighting and fixtures of New York City last year will recognize in this lecture almost a sequel to that, for it is proposed to describe the foreign methods and systems of illumination differing from ours, and also to show some of their more striking features.

It is also hoped that you will be interested in a description of the comparatively new movement abroad for more intense or powerful illumination on congested streets. This movement is now much in favor there and is extending rapidly. After a careful study of it, it may be safely prophesied that once tried it will be in favor here.

As this is the main difference between foreign and American practise in illumination and my time is limited, it will be necessary to make this the main topic and bring up other minor differences in connection with it.

* A lecture delivered at a joint meeting of the New York Section of the Illuminating Engineering Society, and the Municipal Art Society, February 19, 1914.

The Illuminating Engineering Society is not responsible for the statements or opinions advanced by contributors.

[1] TRANS. I. E. S. vol. VIII, p. 199.

LIGHTING OF CROWDED STREETS.

This type of powerful lighting, in its perfection, has really no good examples in New York, and perhaps not in this country until very recently, and generally only where metallic electrode lamps are available. Examples of it exist in several places, usually not sufficiently developed to impress anyone as the impression is given one in Berlin and London. A concrete instance of the lighting referred to is that shown in Berlin, on such streets as the Potsdamer Platz, Friedrich Strasse, Koniggratz Strasse, and in London on Cheapside and Regent Streets. This very powerful lighting is not at all what is known in this country as "White Way" lighting. It is not an attempt to advertise a street or to draw attention to it by some novel decorative design or spacing of the lighting units. It is very strong, permanent, municipal lighting for the purpose of illuminating crowded streets to a point where ease of vision and consequent safety approaches the effect of daylight. In other words, one sees objects by their own reflected light, not as shadows or silhouettes against a lighter background. It was quite a surprise to me when this type of illumination was first seen on a large scale. It appeared that in spite of a consistent effort to greatly increase the intensity of the street lighting in New York, we were still behind the results obtained abroad. We are behind their results on greatly congested streets, but on such streets only. The average lighting in greater New York, some other observers assure me, is as good as if not better than the average lighting of the two best foreign cities, *viz.*, Berlin and London. But when the probable reasons for differences of illumination on congested streets here and there are carefully thought out, they become apparent at once, and while we must admit we are behind in results, we are not behind in the idea or effort to accomplish it.

FACTORS WHICH INFLUENCE LIGHTING DESIGN.

Our problem of the illumination of American cities, in the past, has been so different from theirs that our electrical and gas distribution systems and appliances in certain respects differ considerably. In order to obtain the advantages of the appliances

used abroad, we have only to slightly modify our system and adopt lighting units of a different type in certain congested districts of a city to produce equally good results. We must admit, however, that these appliances are not immediately available for our use in this country.

The problem of the distribution of electricity and gas in this and other American cities has been that of covering a large area of a city and its suburb with an elastic system which could be extended greatly at a minium expense.

The demand upon our manufacturers, then, was to develop such a system, capable of giving a lighting distribution which would result in what may be described as a thin film of illumination extended over a large area. There was no demand until the last five years for a system which would give a comparatively thick film or fairly uniform illumination over comparatively small areas of congested streets. Abroad, however, the conditions in most cities are so different from ours that a demand for heavy, nearly uniform illumination did exist in their congested and narrow streets. The cities abroad are more compact than American cities, have narrower streets and fewer suburbs, and where they have suburbs of great importance, they are taken care of independently.

This compactness probably comes from the fact that most of these cities were fortified until some time not so remote in the last century, and did not spread over large areas—a relic, perhaps, of the old protective feudal system by which proximity to the fortified centre of the overlord was one's greatest safety. From the very reason of clustering within fortifications, or close to them, a congestion in foreign cities developed earlier than the congestion now apparent in our cities, and the demand for more powerful lighting naturally occurred there first. The present city of Berlin is an exception to this, as it is really a modern city without special fortifications such as there are surrounding Paris.

No such problem exists abroad, as in New York, where the question is the lighting of a territory of 321 sq. mi. (831.39 sq. km.) extending from Far Rockaway and Tottenville to the

southern boundary of Yonkers, and which must be provided with nearly every grade of illumination intensity, from that suitable for a country road to that suitable for Fifth Avenue.

They have abroad a firmly rooted prejudice against allowing in cities high voltage currents to be installed on the street in a way that such currents could create any risk of life; so that so far as electric street lamp circuits are concerned, except at a very few points, the highest voltage in the posts in most cities is 480 volts.

If the artist section of the audience will be patient for a few moments while a technical explanation is made to the engineering section, in order to describe the actual differences between the American and the foreign systems, an endeavor will be made to show the differences briefly.

DISTINCTIONS BETWEEN AMERICAN AND EUROPEAN PRACTISE.

In speaking technically of the differences between our lamps and those used abroad, it should be understood that these statements are made strictly with reference to the high intensity lighting of our congested streets and are not reflections on our general systems or their usefulness. In a way, they are also made with reference to my own problem of the lighting of this city, the congested portion of which is mainly in Manhattan and a portion of Brooklyn, where there is a direct current low tension multiple system, fortunately very adaptable to the high intensity electric units used abroad. These units, as stated, are not in use here now; but only slight modifications of our systems are required to make them available.

The demand of American conditions was met by the design and manufacture of the series system of arc lighting, either with constant current, as with the old arc lighting machines, or the later direct or alternating series or multiple enclosed lamps, or the constant current series system as obtained from alternating current by mercury-arc rectifiers. All these systems use a comparatively smaller amperage than the foreign multiple series system; and as the illumination is largely a function of the amperage, it is not relatively as high. In all our direct current multiple lamps a considerable portion of the energy is lost in resistances interposed in each lamp.

In congested areas, the wires or conductors must go underground, and it is not considered the safest practise to carry high series voltages into lamp posts, although in this country such practise is followed to some extent. Consequently, the American high voltage series system does not, in my opinion, lend itself to the conditions of a densely populated metropolitan section of a city. While efforts have been made in the last five years to meet the demand for intense illumination in congested areas, for various reasons, the appliances at hand have not been universally applicable. The metallic electrode type of lamp is not at its best on a multiple low tension system. Multiple enclosed direct current flame arc lamps, with resistances and long, tenuous arcs, are not yet thoroughly satisfactory, although as a laboratory product there is yet much hope of these lamps. The leading foreign authority on arc lamps, however, thinks they never will be satisfactory because when operated singly across 120 volts so much resistance must be provided in the lamp and arc to bring the imposed energy within the operating conditions of the lamps that one loses both in steadiness of illumination and economy obtained per unit of energy supplied.

FLAME ARC LIGHTING.

To meet the foreign conditions, the manufacturers there developed lamps which are operated in multiple series of 2, 4, 6, 8 or 10 lamps across a circuit with a potential of 120-240 or 240-480 volts, having a much higher current density than our lamps. They therefore gave more illumination for the energy supplied. Flaming lamps of this type are available in this country but are quite expensive for the reason that their life is short per trim and the carbons which must be used with them are high in cost, on account of the total expense of importing. The cost of these carbons amounts to a tax of from $40.00 to $50.00 per year on every multiple series open flame lamp operated every night. The total importing expense is from 50 to 60 per cent. of their home value. This is not the case abroad; the carbons are very reasonable in price. One of the foreign manufacturers of open magazine flame lamps advised me that for his 150-hour lamp the carbon cost was one-fifth of a cent per hour. The multiple series lamps used abroad are operated in groups of

about 60, from an independent net work served from the regular mains, with control wires brought back to the central station, obviating in this way the turning on and off of the individual lamp as on our multiple lamps in New York. This is economical, but has some inherent disadvantages.

To sum up, then, the efforts we have made here in trying to make flame arc lamps operate as single multiple lamps across the low tension direct current network of New York have not yet proved quite satisfactory, and to obtain the illumination on certain streets, as provided abroad, our arc lamps must be designed to operate in multiple series across a constant potential system with the amperes or current densities varying for the illumination desired. Such lamps are in use abroad, using 8, 10, 12, 15 and 20 amperes at low voltages, sometimes as low as 35 volts across the arc. They are operated in multiple series, not over ten, between the distributing mains as described, and equipped with substitutional resistance to maintain the rest of the lamps in case of the extinguishment of one or more lamps. The high illumination desired is thus obtained from these lamps with little waste in energy and with more economy per unit of illumination. In other words, we are not getting the illumination per unit of energy that they do abroad, for the reason that to date the American demand has differed considerably from the demand made by foreign cities.

With alternating current flame lamps this trouble does not exist, for the reason that it can be obviated by the use of ratio transformers raising the current density at the arc to the desired point.

To return now to less technical matters. An interesting adaption of our flame lamps in New York to the European idea is taking place now on the suggestion of one of our members, Mr. Rhodes, to put two enclosed multiple or long burning flame lamps in series of two. In this way a longer life of carbons is obtained, less energy is lost and the arc current density increased, so gaining in illumination and economy. Such enclosed lamps in pairs of two in series on the Fifth Avenue posts are placed immediately in front of the Public Library. As you go home it is well worth observing them and making comparison with the single multiple flame lamps on Forty-second Street. Each pair

of these lamps in front of the library takes the same energy, 1.4 kilowatts, as the pairs of standard enclosed lamps used in the other parts of the avenue. The illumination is more than double. This makes a good example of the comparison drawn, bearing in mind the additional cost of carbons, etc.

HIGH PRESSURE GAS LIGHTING IN LONDON AND BERLIN.

In gas lighting, a similar story may be told. Developed probably in Berlin or London about eight or ten years ago, and undoubtedly planned to compete with electricity, the high pressure gas lamp of great candle-power was exploited. In 1909, London sent a delegation to continental cities to note the illumination, and in their report to the London County Council, this type of lighting was highly commended. With the improvements made in the past five years, this lighting has become a decided competitor of electric lighting.

In using the term competitor, it should be qualified by this statement. It is admitted generally that the high pressure gas lamp is not as cheap as the equivalent electric flame arc lamp, and that to a smaller extent it has the same disadvantages of maintenance of rated candle-power as the ordinary small low pressure mantle lamp. The successful use of the high pressure lamp depends largely on the excellence of its maintenance. From the whiteness of the light given when well maintained, it gives an effect of brilliance to a street illuminated by this system that is very attractive, more so than the yellow flame arc lamp used in London and Paris and equalling that of the nearly white flame lamps of German cities. The yellow flame lamp, on account of the reflection of its yellow light from dust and moisture particles in the air, gives an effect of denseness that is almost oppressive when compared with the clear brilliance of the high pressure gas lamp.

To compare with an electric arc lamp of 12½ amperes, it requires a three-mantle gas lamp consuming about 60 cu. ft. (1.70 cu. m.) of gas per hour at a pressure of about two pounds (0.9 kg.) per sq. in. (6.45 sq. cm.). We have no high-pressure gas service or mains for lighting in this city, and, of course, no high pressure gas lamps. In London and Berlin, several miles of

streets are equipped with this system and 'pressed gas,' as they call it in London, is used for interior lighting and particularly for the local application, quickly, of intense heat concentrated in a point for manufacturing operations. In these cities it is stated that a profitable business has been built up in this way.

In operating high pressure gas systems for municipal lighting only, compressor stations, like electrical sub-stations, are established. These take the low pressure gas from the ordinary mains at lighting hours and compress it, using the high pressure mains as their only storage reservoir. Low pressure is on the high pressure mains during the day so that the pilot jets keep burning. As the compressors start to build up pressure on the pipes, the high pressure lamps are so designed as to light at about 700 mm. and, when the pressure falls in the morning, extinguish themselves by the reverse operation. To prevent too sudden application of the pressure to the mantle, the gas is admitted slowly by means of a thermostatic valve, which opens gradually by the action of increasing heat.

EUROPEAN AND AMERICAN METHODS OF AVOIDING GLARE.

There are two other marked differences between foreign and American practise in the placing of the lighting appliances and the methods used to avoid glare.

Abroad, the flame arc lamps and the three-mantle high pressure-gas lamps are placed, with few exceptions, from 3 to 10 ft. (0.9 to 3 m.) higher than our lamps on account of their greater intensity. With this height the foreign authorities consider they have gone beyond the angle between the lamp and the eye of the man on the street within which the effect of glare is produced. With glare so eliminated, they use clear glass globes with flat white enamel reflectors, reflectors which direct the major part of the illumination along angles close to the horizontal line, or prismatic reflectors, and so throw along the street and downwards the full strength of the practically naked light source. In producing the high horizontal illumination of the street plane, they place these powerful sources closer together than we do and hence get the very powerful illumination desired on their crowded streets.

In this way, they really get rid of most of the glare effect, although some still remains.

Here, for the very reason already quoted, on account of our less powerful light sources, we have placed our lamps lower down, thereby getting into the angle of glare; and then to obviate this we use diffusing globes which, while they produce a very agreeable effect, decrease to an appreciable extent the illumination produced. Their method certainly produces more intense and relatively more efficient illumination than that we are obtaining. On the other hand, the effect of our system is more attractive in its softer diffusion. While a number of streets that were much more intensely lighted than Fifth Avenue were observed, not one was as agreeable in appearance.

The many other smaller differences and characteristics of foreign flame lamps and high pressure gas lamps and their use, as compared with American practise, cannot be enumerated here, on account of limited time, although it is my hope to publish them in another paper later. They will be referred to again, however, in connection with the slides to be shown you.

During my trip last summer, many cities were visited: Glasgow, Edinburgh, Manchester, London, Paris, Nurnberg, Berlin, Leipsic, Dresden, Vienna, Zurich, Milan, Florence, Rome and Naples. But of all these cities, only Berlin and London stand out as superior to New York and to the other European cities. Manchester, Birmingham, Glasgow, Paris, Leipsic, Budapest, Strassbourg and Munich all have certain sections of streets and some places or squares lighted on a plan similar to but usually not quite as powerful as that of Berlin and London; but none approach these two cities in the miles of streets lighted in this way. Paris is behind either of them and is still resting on its old reputation of the "City of Light." This reputation was obtained by using small gas-mantle units closely spaced, as will be shown later. Paris is just beginning to use electric flame lamps and high pressure gas lighting.

CLASSES OF STREET LIGHTING.

In Berlin and London, the lighting is graded with the importance of the streets, as to traffic, stores, etc. In Berlin, what may be designated as class A-1 streets, are the Potsdamer

Strasse and Place, Friedrich Strasse, Koniggratz Strasse, Leipziger Strasse, Unter den Linden, Konig Strasse, Invaliden Strasse, etc. In London, the same class is represented by Regent Street, Cheapside, Oxford Street, Whitehall, Haymarket, Piccadilly, Fleet and Cannon Street; in Paris, by the Rue de L'Opera, Rue de Rivoli, Rue Auber, the Grand Boulevards, etc. Similar streets in New York would be Fifth Avenue, from Fourteenth to Sixtieth Streets, Broadway from Fourteenth to Fifty-ninth Streets, Sixth Avenue, from Fourteenth to Fiftieth Streets, Seventh Avenue, from Twenty-third to Fiftieth Streets, and Fourteenth, Twenty-third, Thirty-fourth, Forty-second, Fifty-ninth and 125th Streets, between the limits represented by Fourth and Eighth Avenues, as well as the plazas at the intersections of Broadway and Fourth, Fifth, Sixth, Seventh and Eighth Avenues.

Class A streets abroad are also powerfully lighted. In Berlin, examples of this grade are Wilhelm Strasse, Alexander Strasse, Berliner Strasse, Bismark Strasse, etc.; in London, Farringdon Street, Lower Regent Street and Victoria Street, the Mall, the Strand, etc.; in Paris, Rue de la Paix, Boulevard Malesherbes, Boulevard Raspail, etc.

In New York these streets may be represented by the lower and upper sections of Fifth Avenue and Broadway, Madison Avenue, Park Avenue, Third and Eighth Avenues, and many side streets within the boundaries of the class A-1 streets given above.

The third class of streets, near the centre sections of all these cities, may be termed Class B and C streets, or streets not of special use at certain times of the day, and residence streets. The lighting of these streets is usually by mantle gas lamps with either vertical or inverted mantles from one to four and five in number, depending on the street or sections of it. In many cities, incandescent lamps are also used in the same way, but not, as far as observed, to such an extent as in greater New York. In the lighting of residence streets, the illumination in some sections of the foreign cities is slightly more powerful than that of American cities of the same class; but in the larger number of cities visited, it is not equal to ours and in several it is

inferior. It should be pointed out that in New York the degree of illumination given these streets is generally higher than that of foreign cities and is carried out more uniformly in gas and electric lighting throughout all five boroughs of this city, with due provision for stronger lighting in suburban centers. In this respect, it appears that New York is better equipped than foreign cities, and keeps its minimum lighting above their lowest grade of illumination. At that, on Manhattan Island with its peculiar conditions, this grade of lighting has been justly criticised by experts as too low to properly meet modern conditions. Such ordinary illumination need not concern us, however. It is to the powerful illumination of Class A-1 and Class A streets in Berlin and London that I desire to draw your attention and to give notes as to the points of excellence in other cities as they developed.

While New York, perhaps, started or accentuated the demand for more intense street illumination in American cities, it is not alone in its efforts to get it. The recent installations of magnetite or metallic electrode lamps in Washington and other places, large installations of flaming arc lamps in Chicago, and a recent exhibition trial of high pressure gas lamps in Philadelphia show that there is a necessity for intense lighting and that it is being met in various ways.

ILLUMINATION INTENSITIES.

The term used to express the unit illumination of a surface is the foot-candle. This means the illumination obtained on the inside surface of a sphere of one foot radius from a standard candle of one candle-power placed at its centre. On the Class A-1 streets and places, in London and Berlin, the maximum illumination on approximately the street surface ranges from two to seven foot-candles, much more light in the latter case than is ordinarily used in reading rooms or for general purposes of interior lighting. The minimum illumination on these streets is a quarter to one foot-candle, and usually above half a foot-candle.

In this city the illumination is much lower. Broadway, at Times and Long Acre Squares is probably as highly illuminated as any square we have. The highest illumination found here

was about 1.2 foot-candles. This is largely due to the stores and electric signs, for after these are extinguished, the lighting is much less. The minimum found was about 0.08 foot-candle, when all lighting was on. Fifth Avenue, which is comparable in importance with Regent Street, and really is more important, has a maximum of about 1.7 foot-candles at about 8 ft. (2.44 m.) from a post and a minimum of 0.05—decidedly below that of Regent Street.

It is to be noted, however, that this intense lighting abroad is cut down at least half at about midnight. This is justifiable when such powerful illumination is used. In that case, when half this lighting is turned out, what remains is about an average of ours during the entire night.

In giving the foot-candle measurements of lighting, it should be stated that they were taken by what may be termed reconnaissance measurements of my own and compared with accurate observations from detailed surveys given me abroad. The time was too short for me to make elaborate measurements to establish averages. The surveys were made to check high illumination and get illumination curves between lighting units along the street.

TYPICAL EUROPEAN INSTALLATIONS.

It will now probably be easier to show you the arrangements and appliances for lighting of these foreign cities by slides, pointing out on each slide the points of difference. There are a number of night photographs of the lighting. They are of no scientific value, and the photographs are not even comparable as to intensity; but will give you a good idea of the effect of the intense illumination and the consequent ease and scope of vision.

The difference between seeing on a powerfully lighted street where the minimum illumination is about 0.1 of a foot-candle and a street on which the minimum is about 0.01 is all the difference between ease and discomfort, certainty and uncertainty, safety and danger. Oxford Street is a fair example of this and the photograph shown gives a good idea of the ease of vision.

It is questionable, in my mind, if there is any necessity of going to the very high intensity of the Potsdamer Platz, for instance, where a lighting intensity of over one foot-candle covers

the larger part of this square and the maximum reaches 7.6 foot-candles.

Such intense lighting may be injurious for the reason that the streets leading into such areas cannot be lighted to this extent. If they are dim, the sudden change from ordinary to very intense lighting strains the eye and the driver of an automobile passing rapidly from one zone to the other might be momentarily dazzled or confused.

The accompanying illustrations show street lighting installations in a number of European cities. (Of about 80 slides the following were among the most important ones shown.)

London.—Fig. 1 is a picture of Cheapside, the most powerfully lighted street in London. The maximum illumination along the curb is 2 foot-candles. The average illumination is 1.23 foot-candles. The minimum horizontal illumination is 0.72 foot-candle. The sidewalks are narrow, and with the exception of the hydrants, are free from any obstruction. The magazine flame lamps are suspended from buildings.

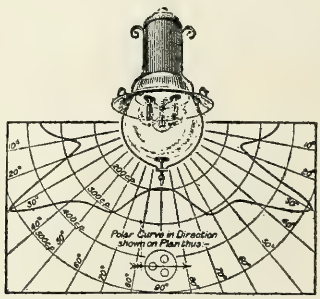


Fig. 2a.—Plan and photometric distribution curve of lamp mentioned in the description of Fig. 2.

Fig. 2 shows Holburn, corner of Tottenham Court Road. Lighting units are placed about 21 ft. (6.4 m.) high and consist of 3 300-watt tungsten lamps burning at highest efficiency. This form of illumination was devised particularly to compete with the white, powerful light of the high pressure gas lamps, and is very successful.

Fig. 2a shows the lighting equipment mentioned in the preceding description.

Fig. 3 is a picture of Regent Street. High pressure three-

Top row: Fig. 1 (left)—Cheapside, London; Fig. 2 (right)—Holburn, London. Lower row: Fig. 3 (left)—Regent Street, London; Fig. 4 (right)—Oxford Street, London.

Fig. 5 (top)—Place de la Concorde, Paris; Fig. 6 (center)—Rue Castiglione, Paris; Fig. 7 (bottom)—Potsdamer Platz, Berlin.

Fig. 8 (left)—Post mantle lantern, Paris; Fig. 9 (center)—Concrete post, Liepsig; Fig. 10 (right)—Ringstrases, Vienna.

Fig. 11 (top) —Flame arc lamp post in Dresden; Fig. 12 (bottom)—A type of arc lamp post in Rome.

mantle gas lamps with clear globes and white interior reflectors, mounted on posts on isles of safety, giving almost complete freedom of sidewalk, and, at the same time, directing the traffic and reducing the cost of lighting installations. This photograph shows the ease of vision given by this powerful lighting system. It is one of the most powerfully lighted streets in London, but is not free from considerable glare. The lighting is very white, very brilliant and as the buildings along the street are nearly all of a light color, the general effect of illumination is very good. The lamps are 135 ft. (41.0 m.) apart; 21 ft. 6 in. (6.55 m.) high; the minimum illumination is 0.2 foot-candle, with a very high maximum near the post.

Fig. 4 is a view of Oxford Street, at night, lighted from posts on isles of safety carrying twin, magazine type, inclined carbon flame lamps. The lighting is not as powerful as that of Cheapside, but ease of vision is maintained. The lamps are 125 ft. (38.1 m.) apart, 23 ft. (7.0 m.) high; minimum illumination 0.11 foot-candle. Maximum, approximately 10 foot-candles.

Paris.—Paris has not advanced as far in high intensity lighting as either London or Berlin, but it is easy to see where its old reputation of "The City of Light" came from. The illuminating effects are obtained by the use of a multiplicity of small gas lighting units spaced closely together.

Fig. 5 is a night view of Place de la Concorde, taken on a bright night. The lamps used in the Place de la Concorde are of two kinds. The ones around the outside circle are vertical 2-mantle lamps. The ones in the inner circle, surrounding the obelisk and fountain, are inverted 2-mantle lamps, placed about 25 ft. (7.6 m.) apart. The difference in illumination between the outer part of the Place de la Concorde and the inner circle, is quite marked at night. The whole effect of the lighting is agreeable and fairly powerful. Photometric tests show, in the center of the ring, a foot-candle intensity which is fairly even, with a maximum of about 1.5 foot-candle.

Rue Castiglione, looking toward The Tuileries from the Vendome column is shown in Fig. 6. The sidewalks are arcaded over and in each arch of the arcade is placed a single vertical gas lamp, about 16 ft. high, and spaced 12 ft. (3.6 m.) apart. The

result is a very uniform illumination on the street level, although by no means a powerful one. The foot-candle measurements showed a very uniform distribution, with an average candle-power in the center of the street of about 0.05 foot-candle. The street is 60 ft. (18.2 m.) wide. The sidewalks, due to the columns, are full of checker-board shadows.

Fig. 8 shows a double vertical mantle lantern and post with ornamental column, also post with two lamps, about the best examples of this type of fixture. These posts and lanterns are used in the Place de la Concorde.

Berlin.—Fig. 7 is a daylight picture of Potsdamer Platz, showing two posts carrying four 20-ampere, 1,100-watt flaming arc lamps, multiple series vertical carbon type. The posts are spaced 148 ft. (45.1 m.) apart. The lamps are at a height of 59 ft. (18 m.). The Platz is illuminated to an exceptional extent, reaching as high as 7.6 foot-candles, according to a careful survey made by Dr. Bloch of the Berlin Electricity Works. The lamps, at the time of test, were equipped with transparent glass globes, slightly clouded. With the extreme height, there was no necessity for the use of diffusing globes.

Fig. 9 is a photograph of lamp posts, in front of a railroad station at Leipsic. This is a very effective cement post. It is one of the most impressive fixtures seen. It is made of cement cast in blocks and laid up in courses like stone.

You will note how these posts match the columns of the railway station, in front of which they are placed.

Vienna.—Fig. 10 is a picture of one of the tall posts on the Ringstrasse carrying a 15-ampere open carbon lamp. All these posts have flowers set in iron baskets on the posts. At Schwarzenberg Platz the arrangement of posts and lamps gives an average horizontal illumination of 0.3 foot-candle.

Dresden.—Fig. 11 is a picture of a flaming arc lamp post near railroad station in Dresden. A good example of the arc lamp posts used abroad.

Rome.—Fig. 12 shows a post holding three arc lamps, in front of Victor Emanuel Monument, Piazza Venezia.

Rome is trying out various makes of lamps, but had not settled on one when I was there They had decided, however, to change

all the vertical mantle gas and gasoline lamps to tungsten lamps. Rome had tried high pressure gas lamps but gave them up on account of a too high cost.

CONCLUSIONS.

It is hoped that with the pictures and their explanations you will understand the remarks made as to the differences between American and foreign practise in illumination and illuminating appliances. You will note that, as far as intense lighting of congested streets is concerned, and in these only, considerable differences occur. In the lighting of all but Class A-1 and Class A streets, we are quite as advanced as they, and as economical when the relative prices of the commodities of gas and electricity are considered.

The use of tungsten lighting, for instance, in New York, far exceeds that of any foreign city and probably antedates them, for it was adopted at an early date in this city, as it was very easily adapted to American systems of distribution, both multiple or series, alternating or direct current.

You will also note from the way they have cleared their sidewalks of incumbrances that congestion is no new problem to them, but one that has been anticipated and taken care of, not only in lighting but in other ways. In this regard the efforts of the borough president of Manhattan are far sighted and wise in both widening the sidewalks and clearing them of incumbrances.

In showing you how European cities have met the problem of lighting their highly congested streets, I hoped to bring to your attention the fact that this same problem is confronting us here and now. To find it, you need only go on certain streets on a winter night from five to nine o'clock, or in the theatre section from half-past ten to half-past twelve any night. Perhaps, New York, on account of its shape and its characteristic lines of travel, developed congestion first among American cities.

While New York has not yet reached London's congestion, it is rapidly approaching it. The great movements of workers from the center of the island to their East side homes early in the evening, the great streams of people flowing to the East River bridges or the tube stations and ferries to New Jersey or to the great railway stations of the city en route to the distant suburbs, need more

intense lighting than is now provided. The great amusement crowds going to, or returning from, the theaters or opera late in the evening, with the great number of automobiles, taxicabs or carriages employed to carry them, need stronger lighting than is now given. This lighting is required not only by the increasing crowds, but on account of the increased number and speed of motor vehicles over the old horse drawn equipment. This element of high speed motors is a very important one and must be carefully considered in meeting the present condition. Taking motors into consideration, it is not so much *what one can get along with,* as *what is really necessary for safety on streets* used greatly for rapidly moving motor traffic. For this and other reasons, more powerful lighting is needed in New York to-day almost as much as it was needed in London, and quite as much as it was in Berlin. This, at least, is the opinion of those of us who have seen this illumination and its necessity. Once installed, it will never be abandoned, for the eye comfort and safety given by it, when properly and judiciously installed, are readily appreciated. Remember that this type of lighting is not used to attract attention to one street, or as a display for advertising purposes on a certain street, as is the practise in some cities, when part of the expense is borne by merchants directly interested in the financial returns. It should be a sustained, consistent, permanent attempt to solve the problem of lighting greatly used streets at night during the hours they are used, so they are safe and one can see easily and instantly any approaching object. If such lighting is adopted in New York, the foreign practise of turning out about half of it at about one o'clock should be followed.

At present, the mileage of this lighting needed is not more extensive than London, or Berlin, and it is a good time to begin and then follow by extensions, as necessary. Nor do we need to follow exactly the foreign practise. It is my belief that a little more diffusion than they have would meet the requirements quite as well, and more agreeably. The bare fact remains, however, that the appliances we need to meet this requirement are not yet available, on account of the difference in distribution systems.

Little prevents their introduction, however; nor is it prohibitive in expense, particularly in electric lighting where it is not dif-

ficult to introduce two lamps in series across 120 volts, if not four or five across 240.

In gas, it means the laying of steel mains along certain streets, which may be utilized for heating, perhaps, during the day time. This, of course, is more expensive for installation than modifying our electric equipment.

It is probable, however, that the question of the adoption of the multiple series type of lamps and their expensive carbons may be obviated, as well as that of high pressure gas lamps, by the use of the new nitrogen-filled tungsten incandescent lamp, which is at once adaptable to our series or multiple circuits, whether alternating or direct current.

When an economical lamp life is obtained and the proper fixtures and glassware are perfected to reduce the great intrinsic brilliancy of this point source light, and provide for the dissipation of the heat developed, there is no reason why it cannot be adopted in place of other appliances for many obvious reasons. It is divisible within the limits of street lighting practise, and if all we hope of it is realized, the problem may have been solved by what is really an American development, splendidly worked out.

In consequence, therefore, in New York we are really marking time, awaiting results and also conducting with this lamp frequent experiments, which promise well, both on the streets and in buildings having great halls, like our armories. For a short time, therefore, no further question of flame lamps or pressed gas need trouble us.

INTERIOR LIGHTING IN UNITED STATES AND ABROAD.

Before closing, your attention should be drawn to one other difference between American and foreign installations that is most interesting to both of the societies represented here to-night; that is, the utter lack of any attempt at artistic, agreeable or diffused lighting of interiors. The usual interior lighting unit in England is the old cotton cord pendant with a bare lamp and an ill fitting porcelain or colored glass reflector. Except for a very few examples where pioneers of the American systems of interior lighting have succeeded in making installations, this is the rule in

England, and only slight improvements are seen on the Continent. This is admitted and deplored by English and Continental illuminating engineers, who say it is only by a slow process of education that they hope to remove it.

The most glaring example I observed was in Westminster Abbey. When you consider that this abbey contains most of the memorials to the progress of the whole Anglo-Saxon race and is really sacred to both America and England, one would expect the lighting to be carefully and perfectly treated. As a matter of fact, except in the chancel and choir, the fixtures in the Abbey consist of curved plain brass tube arms, three or four in number, radiating a foot or so from a plain brass spun ball. This, in its turn, is supported by a short rod ending in a conopy with a hook, suspended from the great height of the arches overhead to a point about 9 ft. (2.7 m.) from the floor by an ordinary cotton covered copper cord, possibly reinforced by a suspension wire. These fixtures are equipped with bare incandescent carbon lamps with porcelain saucer shaped shades.

If this is used in Westminster Abbey, it is not necessary to describe the practise in the rest of England. In justice to illuminating engineering in America, I can say, in closing, that in interior lighting we are far in advance of any foreign practise.

THE VISIBILITY OF RADIATION.*

BY P. G. NUTTING.

Synopsis: New visibility data are given for 21 subjects together with their mean and a formula representing it. Determinations of the ratio of the international candle to the watt are given and also precise visibility data.

The quantitative relation between light and radiation has long been sought by many investigators. Herschel, exploring the spectrum with a thermometer, found that the radiation continued beyond what was visible. The invisible ultra-violet portions of spectra were long ago explored by photography. Langley[1] twenty-five years ago explored the infra-red solar spectrum with his fine wire bolometer and in the visible spectrum measured the amounts of energy of various wave-lengths required for reading print. Pflüger[2] and König and Dieterici[3] determined the relative amounts of energy required to just produce a luminous sensation in different parts of the spectrum. König[4] continued his investigations from the threshold of vision up to an intensity of about 500 meter-candles.

About ten years ago it was clearly recognized that in order to define light in terms of the radiation which excites it, an intermediate function, the visibility of radiation, must be formulated and its constants determined for the average normal eye. Goldhammer[5] in 1905 partly reduced some of König's data and expressed visibility as a function similar in form to that giving the

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

Communication No. 18 from the Research Laboratory of the Eastman Kodak Co.

[1] Langley, S. P.; *Am. Jour. Sci.*, **36**, 359, 1888.

[2] Pflüger, A.; *Ann, Ph.*, **9**, 185, 1902.

[3] König and Dieterici, 28 Psy. Phys. Sinn., **4**, 241, 1893.

[4] König, A.; Ges. Abhandlungen.

[5] Goldhammer, D. A.; *Ann. Ph.*, **16**, 621, 1905.

spectral energy of a perfect radiator, Hertzsprung[6] in 1906 took a rough average of all available threshold data and formulated visibility as a logarithmic hyperbola. The author[7], independently of Goldhammer and Hertzsprung, reduced the data of Langley, Pflüger and König, and in 1907 published this, a function representing it, and the related Purkinje effect and made a rough determination of its principal constant, the maximum ratio of the candle to the watt.

Recently Ives[8] has applied the flicker photometer to the determination of visibility with excellent results and has published data for eighteen different subjects in the region from 0.48 to 0.64μ. I have here to present a similar set of data for twenty-

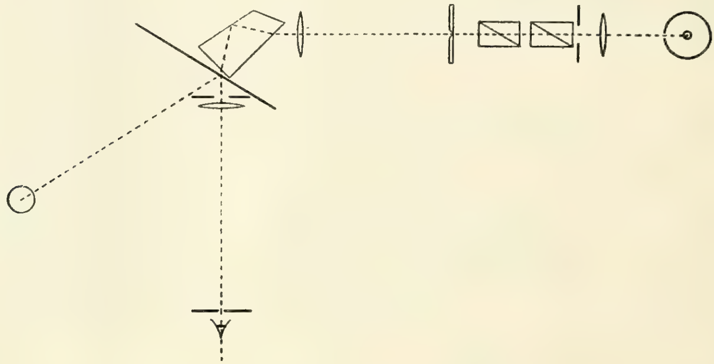


Fig. 1.—Diagram of visibility apparatus.

one subjects with extensions of the visibility curves farther into the red and violet and the results of a direct determination of the maximum ratio of the candle to the watt.

The method of determining the visibility curves was similar to that used by Ives. A wave-length spectroscope was fitted with a Whitman disk flicker photometer so that the pure spectral hue and a white surface illuminated by a standard lamp were viewed alternately (Fig. 1).

Instead of a glow lamp as a source I used one of the acetylene standard lamps designed by Dr. Mees and tested and described

[6] Hertzsprung, E.; *Z. Wiss. Phot.*, 4, 43, 1906.

[7] Nutting, P. G.; *Ph. Rev.*, 24, 202, 1907. Bull. Bu. Stds., 5, 261, 1908.

[8] Ives, H. E.; Phil. Mag., Dec., 1912. See also Thürmel, *Ann. Ph.*, 33, 1154, 1910.

recently by Mr. Lloyd Jones[9]. This is essentially a cylindrical flame from a ¼-foot Bray tip surrounded by a metal chimney in which is a reentrant window screening out all but a horizontal section about 5 mm. high. This source is extremely constant in intensity as well as in quality.

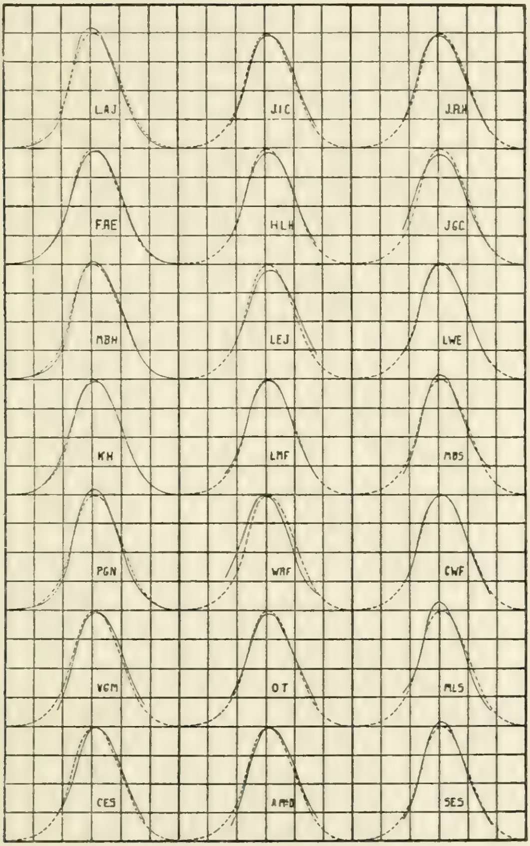


Fig. 2.—Individual visibility curves compared with mean.

Intensities were varied by means of a pair of nicol prisms before the slit, the slit remaining of constant width and therefore the spectrum of constant purity.

The observing pupil was 0.57 x 2.57 mm. throughout, the

[9] Jones, L. A.; Trans. I. E. S.

standard intensity 350 mc. or the equivalent of 241 mc. through a pupil of 1 sq. mm.; test curves run at twice, ½, ¼ and 1/16 this illumination showed that it was safely outside the range of the Purkinje effect.

The energies representing equal luminosities were determined by placing at the ocular a Rubens bismuth-silver thermopile connected to a Paschen galvanometer, both made by Dr. Coblentz. This gave the spectral energy distribution of acetylene in the spectrum actually observed. As a further check, the dispersion

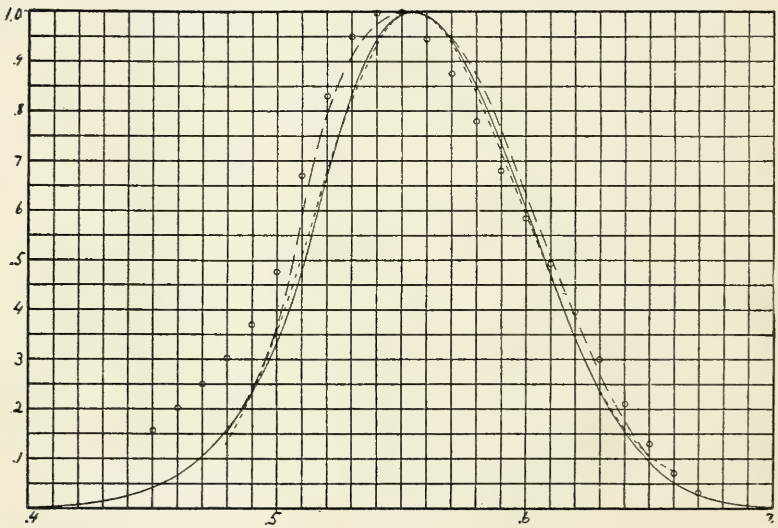


Fig. 3.—Visibility curves.

(o o)—König's data reduced by Nutting, 1907. (— —)—Ives' mean of 18 subjects.
(——)—Author's mean of 21 subjects. (- - - -)—Curve calculated by formula 1.

curve of the spectroscope was determined and the spectral energy computed from the bolometric data of Coblentz and Stewart on acetylene, the two determinations agreed throughout.

The visibility data obtained is summarized in the following tables. Three independent curves were run by each subject on different days. In combining the curves, ordinates were weighted according to height by reducing to equal areas—equal total light in a constant energy spectrum. In Fig. 2 are plotted individual mean visibilities together with the mean of all 21 subjects.

RADIATION VISIBILITY DATA.

Subject	λ0.49	0.50	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.60	0.62	0.64	λmax.
L. A. J...	0.192	0.274	0.715	0.888	1.006	1.042	1.026	0.953	0.842	0.577	0.308	0.132	0.5520
F. A. E..	0.248	0.350	0.662	0.819	0.910	0.967	0.976	0.934	0.863	0.632	0.351	0.160	0.5573
J. R. H..	0.234	0.367	0.705	0.863	0.952	0.982	0.977	0.924	0.816	0.572	0.334	0.149	0.5533
J. I. C...	0.196	0.287	0.610	0.787	0.913	0.970	0.975	0.954	0.886	0.673	0.385	0.188	0.5577
J. G. C...	0.304	0.440	0.751	0.855	0.917	0.947	0.940	0.891	0.810	0.562	0.316	0.147	0.5530
H. L. H..	0.237	0.358	0.686	0.811	0.911	0.963	0.965	0.935	0.859	0.626	0.359	0.175	0.5570
V. G. M..	0.146	0.250	0.618	0.794	0.915	0.970	0.986	0.962	0.892	0.669	0.391	0.183	0.5580
L. E. J...	0.223	0.330	0.612	0.766	0.876	0.929	0.946	0.923	0.857	0.673	0.415	0.202	0.5597
L. W. E..	0.221	0.311	0.679	0.841	0.960	1.010	1.016	0.959	0.863	0.604	0.335	0.146	0.5550
L. M. F..	0.253	0.370	0.688	0.838	0.934	0.985	0.886	0.942	0.854	0.602	0.222	0.163	0.5560
M. B. S..	0.185	0.293	0.650	0.841	0.972	1.036	1.031	0.963	0.829	0.572	0.340	0.223	0.5547
W. R. F..	0.399	0.507	0.796	0.919	0.986	1.000	0.968	0.888	0.775	0.493	0.247	0.144	0.5490
C. W. F..	0.238	0.313	0.701	0.854	0.944	0.988	0.991	0.955	0.871	0.608	0.323	0.130	0.5553
M. B. H..	0.167	0.255	0.626	0.834	0.963	1.023	1.022	0.966	0.870	0.640	0.356	0.173	0.5550
O. T.....	0.263	0.367	0.661	0.804	0.924	0.975	0.967	0.918	0.822	0.593	0.393	0.183	0.5547
M. L. S..	0.290	0.369	0.654	0.884	1.021	1.072	1.049	0.958	0.840	0.534	0.270	0.128	0.5523
C. E. S..	0.223	0.305	0.589	0.760	0.904	0.986	0.995	0.964	0 893	0.664	0.394	0.176	0.5573
A. McD..	0.138	0.245	0.626	0.794	0.918	0.982	0.990	0.950	0.872	0.676	0.393	0.203	0.5553
S. E. S..	0.190	0.300	0.658	0.846	0.972	1.035	1.032	0.908	0.850	0.581	0.333	0.138	0.5550
K. H....	0.245	0.372	0.697	0.851	0.932	0.972	0.979	0.942	0.854	0.595	0.333	0.153	0.5540
P. G. N..	0.182	0.273	0.714	0.878	0.996	1.055	1.038	0.978	0.845	0.568	0.285	0.136	0.5532
Average .	0 227	0.330	0.671	0.835	0.944	0.995	0.993	0.944	0.851	0.605	0.342	0.163	0.5550

COMPLETE VISIBILITY DATA ON FIVE SUBJECTS AND AVERAGE CURVES.

Wave length (μ)	L. A. J.	F. A. E.	M. B. H.	K. H.	P. G. N.	Mean visibility	Ives mean	König (N) mean F, G, H.	Computed from formula
0.400	0.003	0.002	0.002	0.002	0.002	0.002	—	—	—
0.410	0.005	0.003	0.003	0.003	0.003	0.003	—	—	—
0.420	0.008	0.008	0.005	0.004	0.009	0.008	—	—	—
0.430	0.010	0.014	0.008	0.009	0.013	0.012	—	—	—
0.440	0.018	0.026	0.014	0.018	0.020	0.023	0.029[1]	—	—
0.450	0.031	0.047	0.028	0.037	0.029	0.038	0.047[1]	0.158	—
0.460	0.055	0.078	0.049	0.068	0.048	0.066	0.073[1]	0.201	—
0.470	0.089	0.118	0.077	0.112	0.077	0.105	0.107[1]	0.250	—
0.480	0.129	0.170	0.114	0.171	0.118	0.157	0.154	0.302	0.135
0.490	0.184	0.250	0.164	0.254	0.170	0.227	0.235	0.370	0.232
0.500	0.274	0.350	0.255	0.372	0.273	0.330	0.363	0.476	0.358
0.510	0.489	0.489	0.439	0.544	0.430	0.477	0.596	0.670	0.514
0.520	0.715	0.662	0.626	0.697	0.714	0.671	0.794	0.830	0.675
0.530	0.888	0.819	0.834	0.851	0.878	0.835	0.912	0.950	0.824
0.540	1.006	0.910	0.963	0.932	0.996	0.944	0.977	0.996	0.933
0.550	1.042	0.967	1.023	0.972	1.055	0.995	1.000	0.990	0.994
0.560	1.026	0.976	1.022	0.979	1.038	0.993	0.990	0.945	0.993
0.570	0.953	0.934	0.966	0.942	0.978	0.944	0.948	0.875	0.939
0.580	0.842	0.865	0.870	0.854	0.845	0.851	0.875	0.780	0.839
0.590	0.711	0.760	0.763	0.732	0.709	0.735	0.763	0.680	0.717
0.600	0.577	0.632	0.640	0.595	0.568	0.605	0.635	0.585	0.585
0.610	0.428	0.488	0.490	0.462	0.402	0.468	0.509	0.492	0.456
0.620	0.310	0.354	0.356	0.333	0.285	0.342	0.387	0.396	0.343
0.630	0.201	0.237	0.245	0.233	0.196	0.247	0.272	0.300	0.235
0.640	0.130	0.157	0.151	0.153	0.136	0.151	0.175	0.210	0.158
0.650	0.074	0.099	0.080	0.096	0.087	0.094	0.104	0.128	0.108
0.660	0.038	0.058	0.044	0.054	0.051	0.051	0.068[1]	0.070	0.072
0.670	0.019	0.029	0.023	0.026	0.028	0.028	0.044[1]	0.032	—
0.680	0.009	0.013	0.012	0.009	0.013	0.012	0.026[1]	—	—
0.690	0.004	0.007	0.006	0.004	0.006	0.007	—	—	—
0.700	0.002	0.002	0.003	0.002	0.002	0.002	—	—	—

[1] Extrapolated.

The average visibility curve (Fig. 3) for the 21 subjects agrees well with that of previous determinations. It is slightly more contracted than that obtained by Ives, the greatest difference from Ives' mean being on the left (blue) side of the curve near the maximum. The mean wave-length of maximum visibility is 0.555 as against 0.553 obtained by Ives.

In Fig. 3 are included the new data for the violet and extreme red given in the following table for five subjects. These data were obtained by means of the mercury lines 406, 436, 492, 546 and 578 together with helium lines 439, 447, 492, 502, 588 and 568 checked against the acetylene spectrum for energy.

The theoretical formula whose values are given in the above table and plotted in Fig. 3 is the form

$$V = V_m R^a e^{a(1-R)}, \tag{1}$$

in which $R = \lambda_{max} / \lambda$, and $a = 181$. The curve computed for the constants $\lambda_m = 0.555$ and $a = 181$ agrees very well with the data of the new mean experimentally determined curve between wave-lengths 0.48 and 0.65 μ. The departure from the actual curve in the extreme red and violet is of slight consequence in computing the luminosity of sources on account of the relatively low visibility of radiation in those regions.

Now the spectral energy of a normal radiator at a temperature T is well represented in the visible spectrum by the Wien-Paschen function

$$E_\lambda = C_1 \lambda^{-n} e^{-C_2/\lambda T}. \tag{2}$$

Hence the light emitted by such a radiator will be given by the integral of $EVd\lambda$ from 0 to ∞. Call this integral L, then[10].

$$L = A\left(\frac{B}{T} + 1\right), \tag{3}$$

in which $A = C_1 V_m \lambda_m{}^a \Gamma(n+a-1)\,(a\lambda_m)^{-n-a+1}$, and $B = C_2/a\lambda_m$. L has the maximum value

$$L_m = V_m \left(\frac{n-1}{n+a-1}\right)^{1/2},$$

at a temperature

$$T_m = \frac{C_2}{(n-1)\lambda_m},$$

or about 6,530° if we take $n = 5$, $a = 181$ and $C_2 = 14{,}500$.

[10] Nutting, P. G.; *B. S. Bull.*, 5, 305, 1908; 6, 337, 1909. *Applied Optics*, p. 158, 1912.

The remaining visibility constant V_m must be determined experimentally. It is the ratio of the candle (or lumen as preferred) to the watt at the wave length of maximum visibility. The simpler method is to measure in meter-candles as light and in watts as energy some given monochromatic illumination, preferably of a wave-length near that of maximum visibility. The first determinations of V_m were made by this method by Dr. Drysdale[11] and myself[12] seven years ago; we obtained 16.7 and 13.5 cand./watt respectively, values of the right order of magnitude but much too low on account of stray radiation. More recently, Fabry and Buisson[13] have made a determination by this method and obtained the value 55 cand./watt using the green mercury line 5,461 from a powerful mercury arc.

The other method for determining V_m is indirect but less subject to large systematic errors and it gives, under certain conditions, a direct relation between the international candle and the watt. A source of light is used having a continuous spectrum and whose spectral energy distribution is known. With radiometer and photometer, the radiation at a given distance in a given direction is determined in meter candles and in watts per square centimeter, from these total candles per watt is found. Then by graphical integration of the spectral energy and spectral luminosity (energy times visibility) curves, V_m is readily calculated.

For example, suppose that the spectral energy curve has an area A while the measured energy is W meter-watts, then

$$\int E d\lambda = A = W,$$

call the area of the spectral luminosity curve B and suppose the illumination is C meter-candles when and where the energy is W meter-watts. Then

$$V_m \int \frac{V}{V_m} E d\lambda = V_m B = C.$$

By division, $V_m = \frac{C}{W} \frac{A}{B}$, hence knowing C/W by direct determination and A/B by graphical integration, the fundamental constant V_m may be readily determined. The precision attainable by this method depends upon the uncertainties in the three

[11] Drysdale, C. V.; Proc. Royl. Soc., 80, 19, 1907.
[12] Nutting, P. G.; *Elec. World*, June 26, 1908.
[13] Fabry and Buisson, *Compt. Rend.*, 153, 254, 1911.

quantities used (1) relative visibility V/V_m, (2) the specific quality C/W and (3) the spectral energy $E(\lambda)$ of the source used in relative watts per unit difference in wave-length.

I have recently tried the monochromatic method with mercury green light and the total spectrum method with various sources.

Filtered mercury light gave a very low value (4.86 meter-watts to 12.7 meter-candles or $V_m = 2.6$ C/W) in spite of every precaution to screen out the stray radiation and correct for the remainder.

Mercury light dispersed with a high intensity spectroscope gave better results, but the uncertainty is still large owing to (1) the photometric comparison of pure green with white and (2) the removal of the thermopile (or other radiometer) from the spectroscope to face the energy standard. We obtained

220 mc	6.54 mw	38.6 c/w	J. H.
215	"	38.0	N partly rested
320	"	48.9	N rested.

In measuring the brightness, merely looking at anything illuminated with mercury light will greatly depress the eye sensibility to mercury green while the fatigue caused by adjusting the mercury lamp persists for perhaps an hour. Even using a specially designed lamp and every precaution against stray radiation I regard the final result uncertain by 10 per cent.

With the total spectrum method the sources used were acetylene, pentane, Hefner, Nernst (two efficiencies) tungsten and carbon (three efficiencies) lamps. The acetylene source was a Mees standard burner (see above); the pentane and Hefner were primary standard lamps, the Nernst was of Westinghouse make, 1.03 x 13 mm. filament, the tungsten an old type evacuated lamp and the carbon of the "gem" type. The quality determinations (means of three to six) are as follows:

	Observations		Standard quality		Mean horizontal
	mw	mc	w/c	c/w	w/cm²/c at 1 m.
Hefner	6.84	0.871	7.84	0.1276	6.24×10^{-5} watt
Pentane	14.2	1.625	8.75	0.1144	6.97 "
Acetylene	2.45	0.731	1.67	0.598	1.23 "
Nernst 0.80 amp.	21.96	12.42	1.75	0.570	1.29 "
" 0.67 "	13.32	6.46	2.06	0.484	1.64 "
Tungsten 1.20 w/c	5.48	4.94	1.11	0.903	0.884 "
Carbon, 4.0	11.77	2.54	4.64	0.216	
" 3.3	14.20	4.10	4.12	0.243	
" 2.7	16.06	4.58	3.51	0.286	

In calculating the illumination constant V_m, these quality determinations and the above visibility curve (V/V_m) were used. The required spectral energy curves available were, however, found to be inadequate. Either the visible portion is not known with sufficient precision or else the conditions under which the whole curve was taken is not specified with sufficient detail. After these curves have been freshly determined, for the sources whose luminous quality has been determined the constant V_m should be determinable to perhaps 2 or 3 per cent.

In the case of acetylene, spectral energy determinations by Coblentz[14] enable us to evaluate V_m to about 5 per cent. uncertainty. We find for relative integrals of energy and luminosity $A/B = 626/5.66 = 110.6$. For c/w we obtained 0.598, hence $V_m = 66.2$ candles per watt. The uncertainty arises from the uncertainty in the "saturation" of the infra red part of the radiation for the thickness of flame used. I hope soon to have a number of more precise values of V_m.

I am greatly indebted to friends in the photographic and chemical divisions as well as to colleagues in the physics division of the Eastman Kodak Company, who so cheerfully served as subjects in obtaining visibility data. I am particularly indebted to Mr. Felix Elliott, who recorded and reduced nearly all of the thousands of observations.

[14] Coblentz, Bull. Bureau of Standards, vol. VII, p. 291-3.

PLANNING FOR DAYLIGHT AND SUNLIGHT IN BUILDINGS.*

BY L. B. MARKS AND J. E. WOODWELL.

Synopsis: The broad problems that come up in planning for daylight and sunlight in buildings are considered and the state of the art of daylight planning is reviewed. Emphasis is laid on the hygienic value of daylight and sunlight in rooms, and on city planning for good daylighting. The factors that enter into the solution of the problem of providing for adequate and suitable daylighting facilities are discussed and formula are given for the calculation of daylight illumination in buildings. By the simple expedient of a wire frame (representing the solar path) mounted on a small cardboard model of a building made to scale, the penetration of sunlight and obscuration by shadows are quickly predetermined in actual cases. A new instrument for sunlight and shadow determinations is described and illustrated. Daylight illumination measurements in a test room and in several court rooms of the County Court House, New York, are given. The application of the principles involved is illustrated by a discussion of the daylighting facilities of the new New York Court House, accompanied by data, charts and plans of the building and court rooms. A bibliography is appended.

The purpose of this paper is to discuss some of the broad problems that come up for consideration in planning for daylight and sunlight in buildings, and to review briefly some of the steps that have been taken in advancing scientific daylighting of interiors. In illustrating the application of principles involved reference will be made to a recent investigation by the writers of the natural lighting of the court rooms of the proposed new County Court House, New York City.

To the lay mind planning for good daylight in buildings means simply providing plenty of window openings, just as planning for good artificial light means to the novice usually nothing more than providing sufficiently powerful lamps to give a blaze of light at night. The TRANSACTIONS of the Illuminating Engineering Society for the past eight years give evidence that planning for good artificial lighting of interiors is by no means a simple problem and, on the contrary, involves considerations which often

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

baffle even the expert. The mass of data which the Society has published has gone far to give illuminating engineering a definite status especially with reference to the use of artificial light, but thus far has left almost untouched the vital problems connected with planning for the best use of natural light.

As civilization advances we are becoming more and more a nocturnal nation dependent upon artificial light, but this is all the more reason why it becomes increasingly necessary to take the fullest advantage of the benefits to be derived from the use of daylight and sunlight.

In planning for the lighting of buildings our first thought is naturally to provide for illumination that will permit of good vision. But there are other considerations of fundamental and vital importance from a hygienic and pathogenic aspect. Dr. S. A. Knopf, professor at the New York Post-Graduate Medical School and Hospital, in a recent statement submitted to the Heights of Buildings Commission,[1] New York City, laid great stress on the importance of securing adequate daylight and sunlight in buildings to prevent the spread of tuberculosis; he states:

> Tuberculosis, which is propagated by bad air, foul air and lack of sunlight causes annually a loss of 200,000 citizens to the United States. This disease could be largely prevented would we live and work in pure air, in air relatively free from mineral and vegetable dust, and last, but not least, would we construct the buildings in which we live and labor so as to allow sunlight to enter more freely.

At a recent meeting of the Municipal Art Society a prominent speaker said:

> I read in my newspaper to-day of the benevolent project to build a great hospital for consumptives, the victims of tuberculosis, where they may have air and sunlight. And in the same paper I read of plans for a 30-story building. What are we trying to do? What do we mean by putting up these horrible structures, to the lower floors of which no light can ever penetrate? We build hospitals for the poor consumptive, and then we turn around and erect sky-scraping structures where consumption may breed, so that we shall not lack for patients.

In areas where high buildings are crowded together most of the rooms even on the street front are inadequately lighted and

[1] Report of the Heights of Buildings Commission, New York City, December 23, 1913. This report contains a mass of valuable data relating to building regulations, etc., and has been freely quoted herein.

many are decidedly dark. In the lower section of New York City where the office buildings range from ten to twenty-two stories high, it was found by the Heights of Buildings Commission that on a bright day at noon in mid-summer artificial light was being used next to the windows in almost all of the street rooms. The conditions in the interior courts in parts of the tall building district are even worse. Fig. 1 gives an illustration of the conditions found in this district. The black windows indicate where artificial light was being used near the windows at noon on a bright summer day.

BUILDING CONDITIONS AND REGULATIONS.

Regulations Based on Street Width.—In planning for the artificial lighting of buildings we locate our light sources inside of the buildings and therefore need not consider whether the buildings are high or low, close together or far apart; but in planning for daylighting, especially in cities, the height of buildings, their shape and distance apart are naturally fundamental considerations; hence many municipalities have passed regulations restricting the height of buildings and specifying the minimum street width.

For example, in New York City the height of tenements is at present limited to 1½ times the width of the widest abutting street. In the second class cities of Massachusetts, no tenement may have more than one legally habitable floor for each full 10 ft. (3.0 m.) of street width, unless it is set back from the street a distance equal to the excess of its height over that permitted at the street line. The height of other buildings is limited to 125 ft. (38.1 m.). In Chicago, the height of tenements is limited to 1½ times the street width while the height of other buildings is limited to 200 ft. (60.9 m.). In Boston, the height of all buildings is limited with the exception of coal hoists, grain elevators and sugar refineries.

In European cities the limitation based on street width is in most cases the fundamental restriction on the height of buildings. In America this restriction at present plays a much less important part. It may be said to be fundamental in the general height restrictions of Washington and to be of great practical impor-

tance in the buildings of Boston. It is also a very important factor in height restrictions for tenement houses.

In Boston, except as above noted, Charleston, Cleveland, Erie, Fort Wayne, New Orleans and Youngstown, the height of buildings is restricted to 2½ times the width of the street. With Washington, these cities are the only cities in America that base the general height limitation of all buildings on the street width. Washington is the only city that bases the permissible height of buildings upon the width of the street diminished by an arbitrary amount; the height of buildings on residential streets more than 70 ft. (21.3 m.) in width may not exceed the width of the street diminished by 10 ft. (3.0 m.). In cities of the second class (population 50,000 to 175,000) in New York State, no building to be used for living purposes, except a hotel, may exceed in height the street width nor in any case may exceed 100 ft. (30.5 m.) in height.

Regulations Based on Maintenance of a Minimum Angle of Light.—A limitation based directly on street width maintains a constant minimum angle of light for the front of the building at the ground floor. If the prescribed height is equal to street width this minimum angle of light is 45 deg.; if 1½ times street width, it is 33⅔ deg.; if 2 times street width, it is 26½ deg.; if 2½ times street width, it is 21⅔ deg. The converse of this is that the maximum angle of light obstruction will be the difference between the above amounts and 90 deg., *i. e.*, 45 deg. for height limit equal to street width; 56⅓ deg. for height limit 1½ times street width; 63½ deg. for height limit 2 times street width; 68⅓ deg. for height limit 2½ times the street width.

From Fig. 4 it is clear that a flat limit of height is not necessary in order to secure a minimum angle of light. If the height limit based on street width is made to apply only to the elevation of the building at the street line and other portions of the building are set back in the same ratio as height limit to street width the angle of light is maintained. If the height limit is twice the width of the street a set-back after reaching the height limit at the street line of 5 ft. (1.5 m.) for every 10 ft. (3.0 m.) of increase in height will maintain the angle of light at 26½ deg.

In London, the angle of light is more expressly stated. The

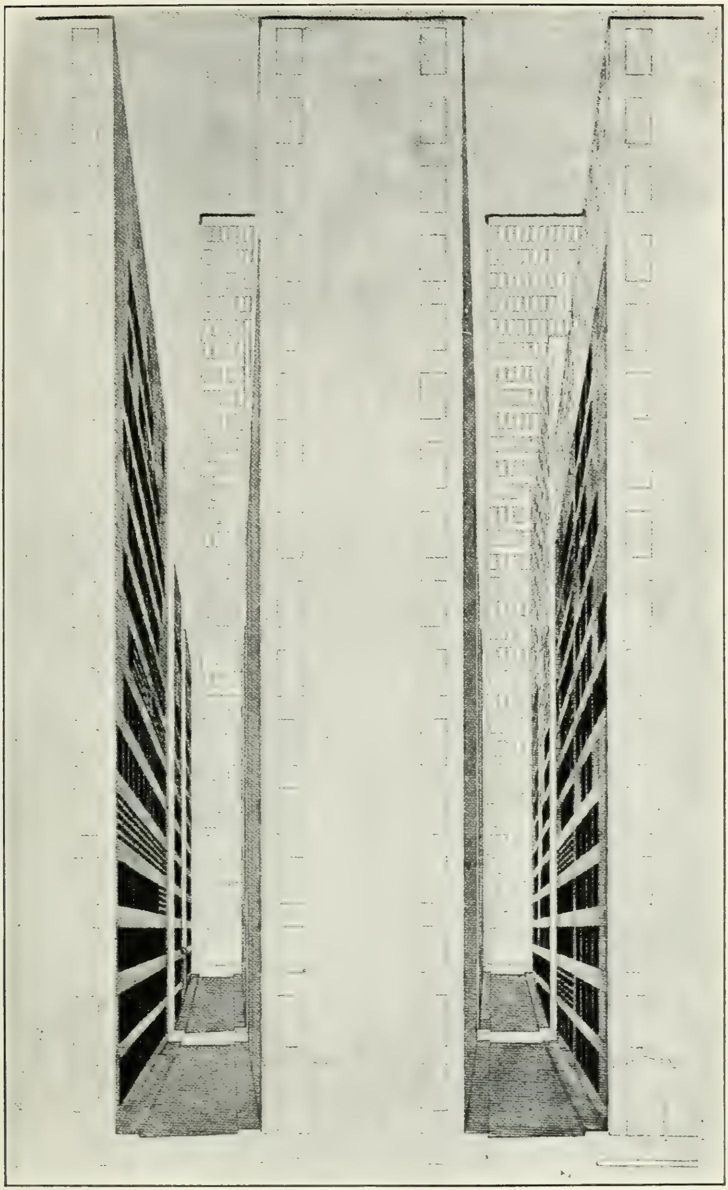


Fig. 1.—Use of artificial light in offices on Exchange Street, New York City. The black windows indicate where artificial light was being used near the windows at noon on a sunny summer day.

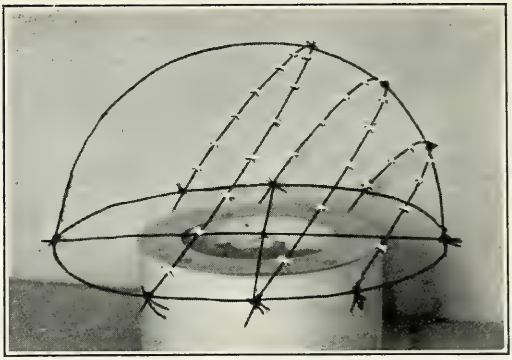


Fig. 2.—Cardboard model of New York Court House made to scale showing wire frame (representing the solar path) mounted to determine penetration of sunlight and obscuration by shadows.

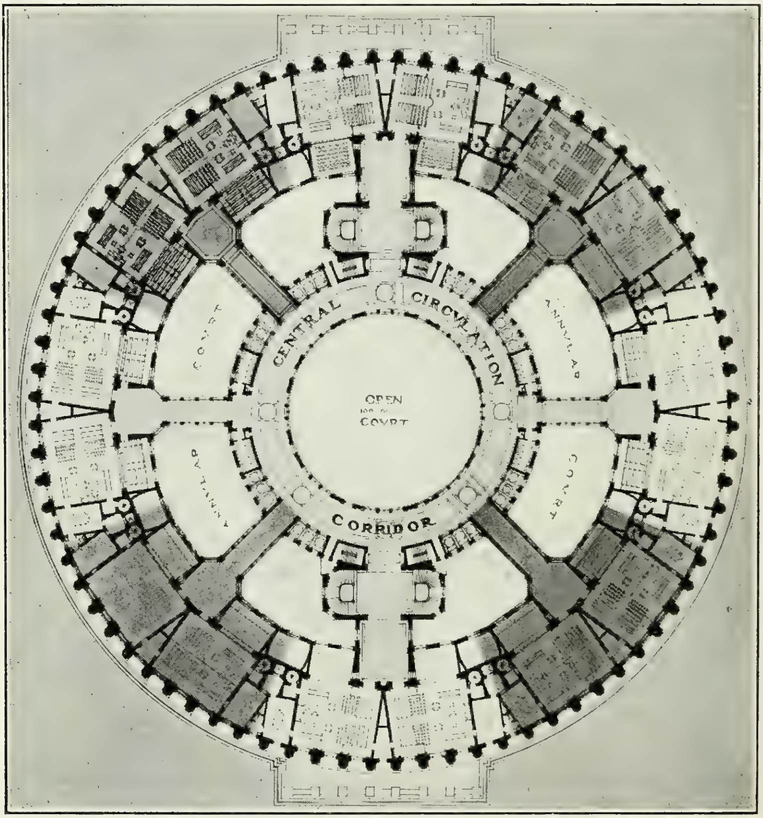


Fig. 3.—Architects' typical court room plan, No. 3, new County Court House, New York City, showing by shading the grouping of court rooms into separate units.

rear heights of a building are generally regulated by a line drawn at an angle of 63½ deg. to the horizontal toward the building from the rear line of the lot. That is, a building may not be built so as to obstruct the light of the adjoining lot in the rear at an angle of more than 63½ deg.

Height Limitations in American and European Cities.—The maximum height limit in America is, as a rule, set so high that it limits the height of buildings only when what might be termed the logical height limit for that particular city or locality has been very much exceeded. In other words, the maximum height limit is no height limit at all so far as most buildings are con-

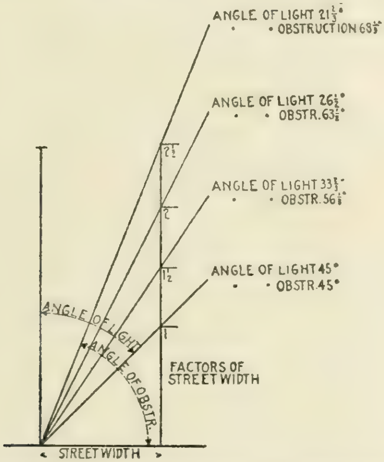


Fig. 4.—Angles of light and of light obstruction on ground floor on street front.

cerned; it only prevents the erection of a few exceptionally high buildings. It does not limit or condition the character of the great mass of buildings erected even in the central business district. In Boston, Chicago, and Washington, however, the present maximum height limits do constitute a very practical restriction, as evidenced by the tendency in certain districts to build up to the full height allowed by the restrictions.

A tabulation of height limits in some American and European cities is given in Appendix I.

DAYLIGHT.

Determination of Sky Obstructions.—In most cases, planning

6

for daylight involves consideration of sky obstructions, such as buildings or other structures, or natural objects such as an adjacent hill or mountain, etc. The interception of daylight by such sky obstructions depends upon several factors, the most important of which is the average height of the sky obstruction and its position upon the horizon with reference to the room or building. For example, a tall adjacent building situated off to one side within the line of light intercepted by the window apertures will have little influence in reducing the light entering the room, whereas if the same building were situated directly opposite the window of the room, it would result in cutting down a large proportion of the daylight that would otherwise enter the room. Similarly, a long line of low buildings or distant buildings would have a very much less effect in diminishing the light entering the room, than would a corresponding area of sky obstruction situated at such a point as to intercept the light that would otherwise enter the room at higher and more favorable angles.

1. *Photographic Method.*—A sky obstruction forms an artificial sky line which is above the natural horizon; it represents the outline of buildings and ground or other obstructions. This sky line can be approximately determined by taking a series of over-lapping photographs of the horizon from the same station, the series to include such portion of the entire horizon as it is desired to show. By properly joining, a panoramic view is secured showing the actual sky line formed by the obstructions. The natural horizon (which will be a horizontal line drawn across the center of the picture if the camera is held level) is first determined on the panorama, and from the known angle of the camera lens (corrected for distortion) parallel lines representing the degrees of altitude above the natural horizon can be drawn on the panorama, from which the altitude of the artificial obstruction may be determined at any point of the compass.

2. *Mathematical Method.*—Another method for determining the artificial sky line consists in measuring or determining from a map the distance from the point at which it is desired to determine the results, to given obstructions and at the same time using the known height of each obstruction from which the altitude in degrees of each obstruction can be readily figured

and an artificial sky line plotted. Except in the simple cases this method involves much more work than the photographic method.

The object of such a panorama is to determine the percentage of sky obstructed in a given direction, and this may be determined with sufficient accuracy by drawing upon the photographic panorama or graphically constructed sky line, horizontal lines representing the degrees of altitude (5 deg. intervals are generally sufficient). The approximate area of sky obstructed in each of the zones of altitude may then be easily determined by inspection or, if more accurate results are required, by means of a planimeter. In view of the fact that the panorama is drawn with horizontal and vertical co-ordinates, and is on a plane surface instead of being upon the surface of a sphere representing the visible sky, it is necessary to multiply the area of obstruction in each separate zone of altitude by a factor which will give the proper weight to each of the horizontal zones. The approximate factors or relative areas for each 5 deg. zone from the horizon to zenith are given in the accompanying table. Typical sketches showing sky lines determined in accordance with the above methods are shown in Appendices 4 and 5.

Table giving relative area of zones at 5 deg. intervals from horizon to zenith; horizon of 180 deg. with radius unity:

Zone: degrees above the horizon	Factors or relative areas
0 deg. to 5 deg.	0.2738
5 " " 10 "	0.2716
10 " " 15 "	0.2675
15 " " 20 "	0.2613
20 " " 25 "	0.2532
25 " " 30 "	0.2432
30 " " 35 "	0.2310
35 " " 40 "	0.2173
40 " " 45 "	0.2020
45 " " 50 "	0.1855
50 " " 55 "	0.1670
55 " " 60 "	0.1475
60 " " 65 "	0.1264
65 " " 70 "	0.1048
70 " " 75 "	0.0824
75 " " 80 "	0.0593
80 " " 85 "	0.0358
85 " " 90 "	0.0120
Total area of quarter sphere representing the sky visible between horizon and zenith with horizon of 180 deg.	3.1416

It is also possible to determine from such a panorama the average angle of sky obstruction, and the consideration of this angle is an important factor in planning for daylight, as it is obvious that a sky obstruction at a very low angle will be very much less effective than a sky obstruction at a higher angle, and also that the depth of the room and the angle which may be considered the most favorable for the entrance of light in a given room will have an important bearing in determining the reduction caused by the sky obstruction. The effect of these sky obstructions will also depend to a considerable extent upon the color and reflecting power of the obstructions which in the case of buildings may modify the effect materially. For example, a tall building of light color may return a great deal (often more than 50 per cent.) of the light received by it, and present a surface which may have a brightness as great as if not greater than that of the sky.

In taking account of the effect of sky obstruction in planning for daylight in a given case, it is necessary to consider not only the existing factors and conditions so far as they may be determined, but also the possibility of *future* changes in buildings, etc. The four general cases which are encountered are:

1. Unobstructed sky;
2. Partly obstructed sky—buildings of low diffusion;
3. Partly obstructed sky—great diffusion;
4. Sky completely obstructed.

To determine comparative results quantitatively for the four cases, the most practical way is to make tests by a luminometer under conditions which most closely resemble those of the problem in hand; such tests must of course be made under conditions which are most typical and representative of the working conditions under which the daylight is to be used in the building or rooms for which its utilization is being planned.

The variations due to the seasons of the year in the presence or absence of snow on the ground, and the orientation of the building with reference to the points of the compass, etc., etc., should be given due weight.

Illumination Due to Direct Light from the Sky on the Vertical Surface of a Window of a Building Front, with Obstructed Uniform Horizon.—In Fig. 5, let A and B represent the buildings

on the opposite side of the street of width W. The formula for determining the illumination on the vertical window at point of observation *a* in building A in a case where the building B opposite is of constant elevation H above the point of observation *a* is derived as follows:

The sky may be represented by a spherical surface with its center at the point of observation *a*. A plane passing through the point *a* and through the top line of the opposite building front cuts a circle from the surface of the sphere drawn to represent the sky, and the opposite building obscures all the direct light from the sky which would otherwise enter below the plane drawn through *a* and the top line of the front of building B, and the

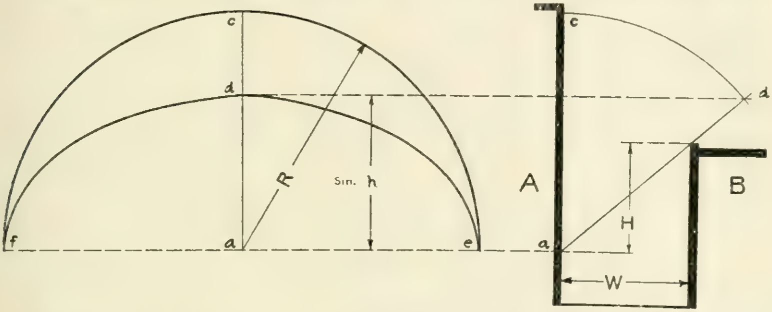


Fig. 5.—Illustrating the derivation of the formula for determining the illumination due to direct skylight falling on the vertical surface of a window of a building front with obstructed uniform horizon.

amount of sky obstructed may be represented graphically by the projected intersection of this plane with the spherical surface drawn to represent the sky, giving the semi-ellipse e-a-f-d-e. The projected area of the visible sky is therefore the lune f-c-e-d-f. The area of the semi-ellipse is the area of the semi-circle on the sphere projected on the plane through *a* and *c* as shown by the semi-ellipse and is equal to:

$$\tfrac{1}{2}\pi R^2, \ \sin h$$

where h is the angle between the line ad and the horizontal. Subtracting this area from that of the semi-circle e-c-f, $\tfrac{1}{2}\pi R^2$, gives:

$$\tfrac{1}{2}\pi R^2(1 - \sin h)$$

for the area of the lune.

If B represents the brightness of the sky in candles per square foot, the illumination at *a* in foot-candles will be:

$$I = \tfrac{1}{2}\pi\, B\, (1 - \sin h).$$

If we use W as the width of the street, that is, the distance from A to the face of the building, and H as the height of the opposite building front, not above the ground, but above the point of observation, *a*, we can express sin *h* in terms of H and W, thus:

$$\sin h = \frac{H}{\sqrt{H^2 + W^2}}$$

and our expression for the illumination at *a* becomes:

$$I = \tfrac{1}{2}\pi\, B \left(1 - \frac{H}{\sqrt{H^2+W^2}}\right) \dots\dots\dots\dots\dots\dots (1).$$

Illumination on a Horizontal Plane within a Room.—The illumination directly due to the sky at a point on a horizontal plane in a room depends on, (*a*) the amount of sky visible from that point, (*b*) the brightness of this area of sky, and (*c*) its anguar elevation. If the light comes through vertical windows, the solid angle subtended by the visible sky at any working position in the plane of reference is usually small enough for the illumination in foot-candles there to be given by the formula:

$$I = B\, \omega \sin \theta \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2).$$

Where B, represents the brightness of the sky in candles per sq. ft.
ω, the solid angle subtended by the visible sky at the test station.
θ, average angle of elevation.

The solid angle may be expressed in "square degrees" as used by Weber and Cohn, and more recently in the British committee report on daylight illumination of schools in which the recommendation is made that "The darkest desk in any school room should receive an illumination equivalent to that derived directly from 50 reduced square degrees of visible sky." A square degree is equal to the solid angle subtended by a square each of whose sides subtends one angular degree.

Factors Governing Daylight Admission.—The amount of daylight available from a window depends upon—

(*a*) The size, shape, depth and position of the window opening.
(*b*) The brightness of the sky.
(*c*) The sky angle, that is, the angle formed by a vertical plane passing through a window in the wall of a building, and a line from the window through the top of the opposite building. (In the case of an unobstructed horizon the sky angle is 90 deg.)

(*d*) The diffusion from the street surface and from adjacent buildings.

(*e*) The character of glassware in the windows.

Only a comparatively small percentage of the flux of daylight that reaches the window is effective in the illumination of the interior. The effect of blinds, curtains and other decorative and absorbing media in obstructing the entrance of light is often considerable. Furthermore if the color of the walls and furnishings is dark a large portion of the light is absorbed.

Fig. 6 shows two windows of equal area, one of which is vertical and the other horizontal. These two windows will give very different results in the lighting of a room. Daylight will

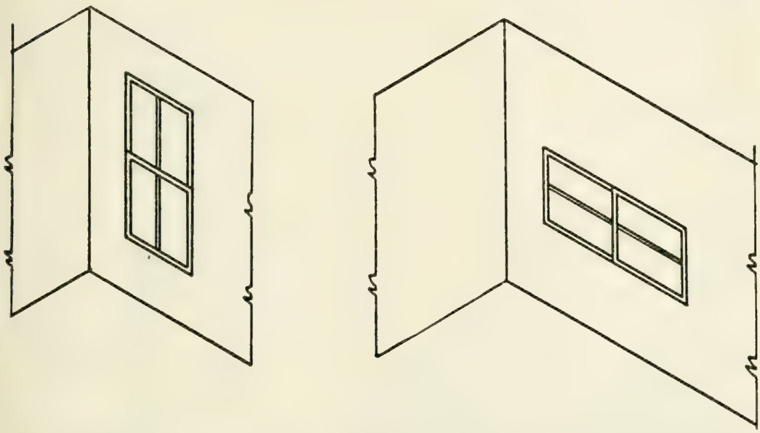


Fig. 6.—Windows of equal area. Daylight will be received through the vertical window at a much more favorable angle for interior illumination.

be received through the vertical window at a much more favorable angle for interior illumination, even with an unobstructed horizon in both cases. If the sky is obstructed for some little distance above the horizon the vertical window will have a still greater advantage over the horizontal.

Obstruction to Light at Window Openings.—It is customary to determine limiting angles at which the light is completely intercepted by window walls, cap stones, columns and other obstructions to light; for example, in Fig. 7 the daylight received in the Court House window shown is from a horizontal visual angle of 129 deg., and from a vertical visual angle of 73 deg.; from such

measurements the proportion of the total amount of daylight intercepted by the windows may be determined.

Relation of Window Area to Floor Area, etc.—With reference to the size of the windows for a given interior room, certain ratios are frequently used as a basis for design and comparisons. Among the ratios used are the following:

Ratio of window to floor area.
Ratio of window area to depth of room.
Ratio of height of windows to depth of room.
Ratio of window area to outside or window—wall area.

In some classes of interiors the ratio of the area of the window space to the floor area to be lighted is sometimes specified to be

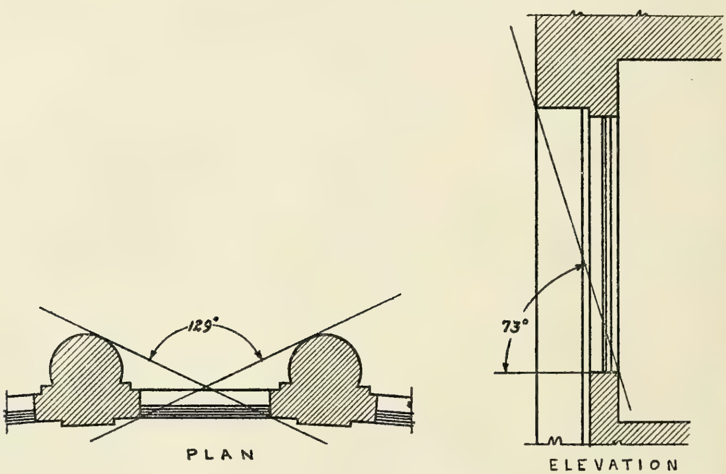


Fig. 7.—Plan and elevation of a window showing obstructions to admission of daylight and limiting horizontal and vertical visual angles.

1 to 4 or 1 to 5, as in factories for example; while in other cases such as office buildings, this ratio may be specified as 1 to 7 or 1 to 10, etc., depending to some extent upon the depth of the room. This system of computation, however, is evidently limited in its application, because the ratio of window space to floor area taken alone does not give a true relative value of daylighting facilities. For example, the ratio of window space to floor area for the lower floors of a building might be quite different than that of the upper floors for equivalent illumination, especially if

part of the direct light of the sky is cut off by an adjacent tall building.

While the ratios above referred to are often of considerable value in comparing the window openings of rooms of the same character, arrangement and exposure, the relative values indicated may be very misleading, as for example where the shape of a room is quite out of the ordinary or where windows of unusual shape are provided.

Limiting Angle of Light.—Account is frequently taken also of the angle of a point half way between the top and bottom of the window and a given reference point within the room, such as a point 2 ft. 6 in. (0.76 m.) or 3 ft. (0.9 m.) above the floor at a working distance near the most distant wall; account is also taken of the angle between such a reference point and the top of the window.

Light-value of a Window.—It has already been pointed out that the ratio of the window area to the floor area taken alone may convey a very imperfect and even erroneous idea of the amount of daylight that reaches an interior. This is clearly shown in Fig. 6 previously referred to, in which two windows of the same area but differently located with respect to floor space, obviously give very different results in lighting. The ratio referred to does not take cognizance of the effect of obstructions outside of a window, of the amount of sky visible, of the contour and depth of the window or of the height and depth of the room. Prof. L. Weber of Kiel, Germany, introduced the conception of the "light-value" of a window to give a more correct basis for estimating daylight entering a window. The "light-value" is the ratio between the actual illumination of the vertical window pane and the illumination which would be received from an unobstructed sky; that is to say, the ratio between the solid angle subtended at the window by the visible sky to the solid angle subtended by the sky with free horizon.

If this quantity is modified so as to include the percentage of the window area through which unobstructed sky can be seen it becomes even more useful. If the light value be denoted by L and this be multiplied by the permissible ratio of window space to floor area we obtain a new quantity, P, which is a measure of

the usefulness of a window for admitting daylight. Having determined L, we have $P = L.\frac{g}{b}$ where g is the area of the glass surface of the window and b the area of the floor of the room. This formula is of course limited in its application as explained in the preceding paragraph.

Ratio of Indoor to Outdoor Daylight.—Cohn found that a school room was sufficiently lighted by day if the minimum horizontal intensity on any desk was about 2½ foot-candles. Weber found that with the average value of the sky brightness likely to be met during the hours of study, this illumination should be obtained on any desk in a school room receiving 0.5 per cent. of the unobstructed daylight illumination out of doors; that is to say, 0.5 per cent. of unobstructed roof light. As the vertical window is exposed to only one half of the sky with a free horizon, the figure given by Weber is equivalent to 1 per cent. of the daylight on the window sill.

Window Glass.—In cases where buildings are necessarily built close together or where it is impracticable to secure a reasonably unobstructed horizon, it is possible to redirect the light from the sky by means of prismed windows. By this means the light in the rear of a room say 60 ft. (18.3 m.) deep may easily be increased to from 10 to 15 times, though it must be understood that the total flux of light in the room is not increased by the substitution of prismed windows for clear glass.

When windows are equipped with prismatic glass the incident rays of daylight are deflected from the course which they would naturally take if plain glass windows were used and instead of striking the floor at points near the position of entry of the light, the rays reach the inner portions of the room thus lighting parts of the working section where more light is required.

In the crowded tenement districts in large cities the substitution of daylight prisms for ordinary glass would be a boon to those who are now compelled to live in rooms that scarcely see the light of day. Fortunately the movement now on foot to enforce regulations providing for direct daylight and sunlight in tenement houses will soon make the dingy tenement a thing of the past.

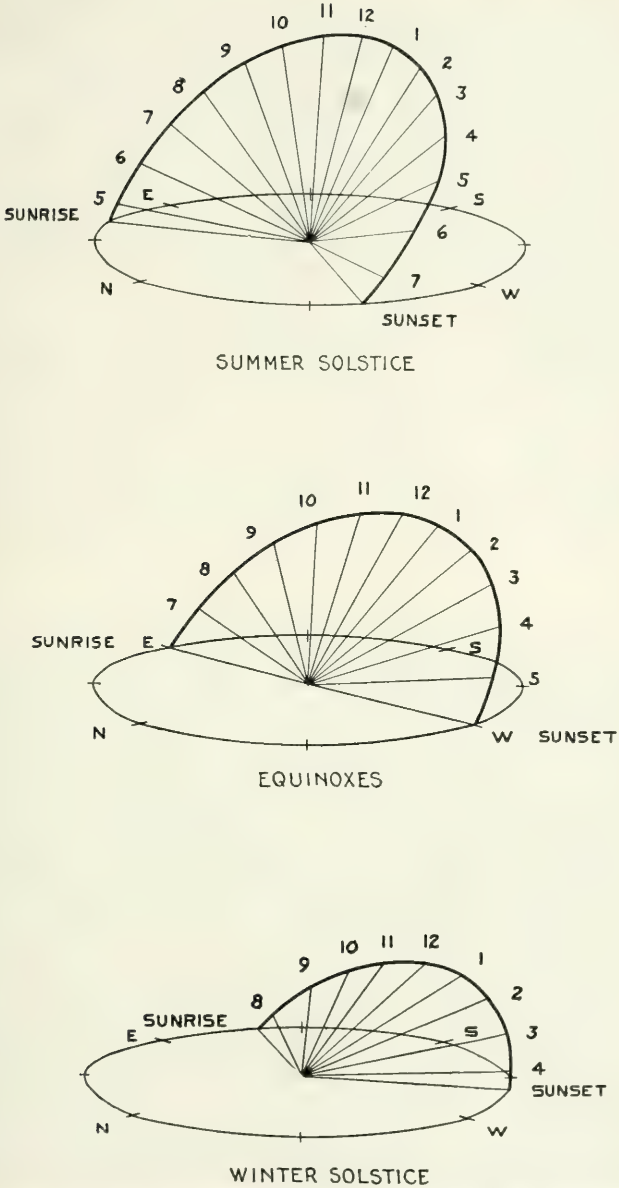
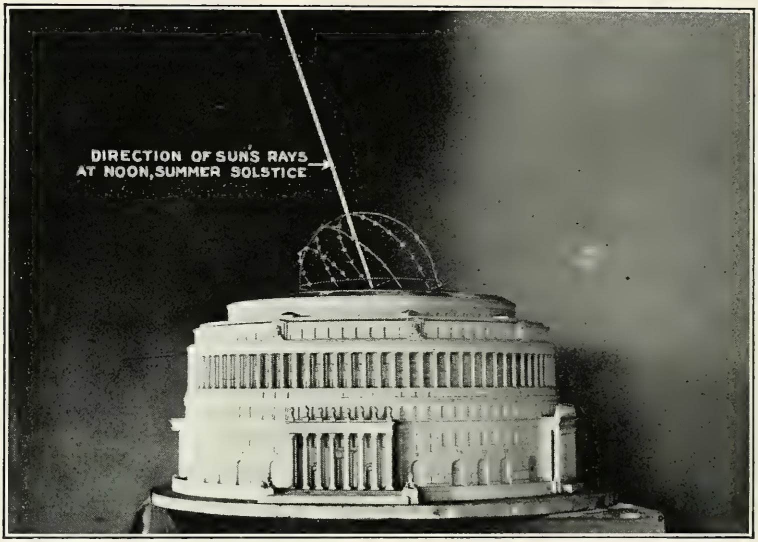


Fig. 8.—Apparent path of the sun at latitude of New York City illustrating angles of sun light at different hours of the day at the solstices and equinoxes.



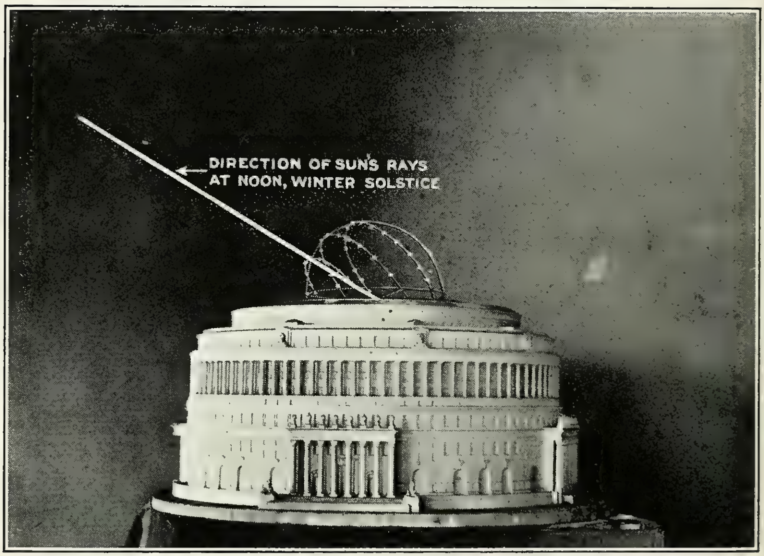


Fig. 9.—Plaster model of new County Court House, New York City, showing wire frame (representing the solar path) mounted to determine direction of sun's rays for all seasons of the year.

SUNLIGHT AND SHADOWS.

Variations Due to Latitude, Seasons of the Year and Hours of the Day.—The apparent path of the sun at the summer and winter solstices and the equinoxes for latitude about 41 deg. north (approximately that of New York City) is shown in the perspective diagrams, Fig. 8. These diagrams also show the angles of sunlight at the different hours of the day, solar time.

In order to determine in a practical way the direction of the rays of the sun at any hour of the day for the winter and summer solstices and the equinoxes, a simple frame representing the celestial sphere was constructed of wire with the apparent sun paths shown by wire circles as indicated in Fig. 2. The common axis of the circles representing the apparent paths of the sun makes an angle with the horizon corresponding to the latitude chosen, namely 41 deg. in this case. Hour marks (consisting simply of pieces of twine, knotted) were placed at 15 deg. intervals on each of the three circles. Another circle of wire was placed on the north and south axis of the wire frame, and the points of intersection of this circle with the circles representing the apparent paths of the sun, correspond with the zenith or twelve o'clock position of the sun, solar time. By placing an artificial light source of small size at some distance from the wire frame the direction of the rays of the sun could be reproduced for any hour of the day, or for any of the four seasons of the year by locating the artificial light source at such a point that the rays of light are in line with the desired hour of the day on the sun path circle representing the season chosen and the center of the wire frame corresponding with the center of the celestial sphere. The wire frame may then be mounted on a miniature wood or cardboard scale model of a building or buildings adjusted to correspond with the points of the compass established by the wire frame. By using models of light color, a partially darkened room and a concentrated beam of light from a miniature lamp with parabolic reflector, it is possible to secure clear, sharp shadows on the scale models, sufficiently accurate to form the basis of conclusions with respect to the penetration of sunlight and the obscuration by shadows in any given case

From the observations thus taken drawings or charts may be made showing the direction of the sun and the shadows produced during any period of the year and for various hours of the day between sunrise and sunset.

Fig. 2 shows the wire frame set up on a small model made to scale for the purpose of determining the shadows cast by the inner court and connecting bridges on the inner wall of the proposed new County Court House, New York City. Typical shadows thus determined are shown in Appendix No. 6. The degree of penetration of sunlight in the court rooms during the working year was determined by this method.

The use of this wire frame for determining the direction of the rays of the sun on the large scale model of the court house is shown in Fig. 9. Some idea of the great change in direction of light due to the change in the path of the sun from the winter solstice to the summer solstice, and the consequent effect upon the production of the shadows at different times of the year may be obtained by reference to this figure.

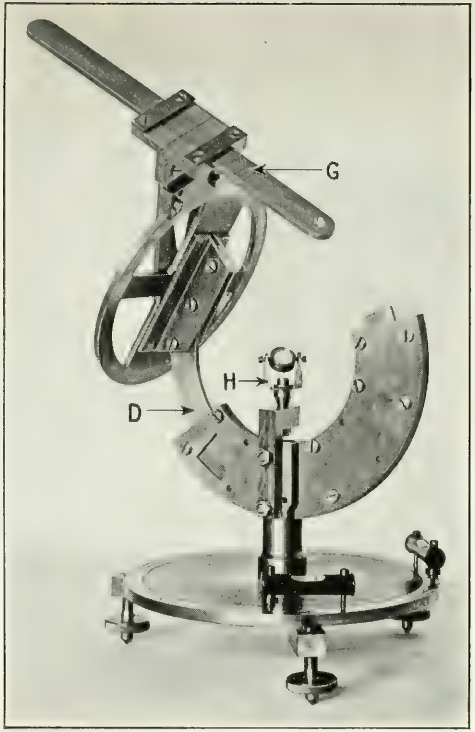
Molesworth's Planisphere Diagram.—Molesworth[2] describes a unique, graphical method whereby with the use of the planisphere,—or the plane projection of a sphere,—the hours during which any particular window receives direct sunlight can be determined. This method is mathematically correct, but requires the following data with regard to each obstruction, namely:—

- (*a*) The angular elevation of the different salient points.
- (*b*) The true bearing of these points.
- (*c*) The true bearing of the side of the building in which the window is located.
- (*d*) The latitude of the place.

As this information is often difficult to obtain, and must be secured for each important obstruction on the visible horizon, considerable time is required to obtain a definite result, even for one season of the year and the process must be repeated if the information is required also for other times of the year.

The determination of shadows by means of models is much simpler than that by the use of descriptive geometry or calculation, or by the graphical method of using a planisphere diagram. Moreover the models may be readily shifted to study the effect

[2] Molesworth, H. B.; Obstruction to Light; London, 1902.



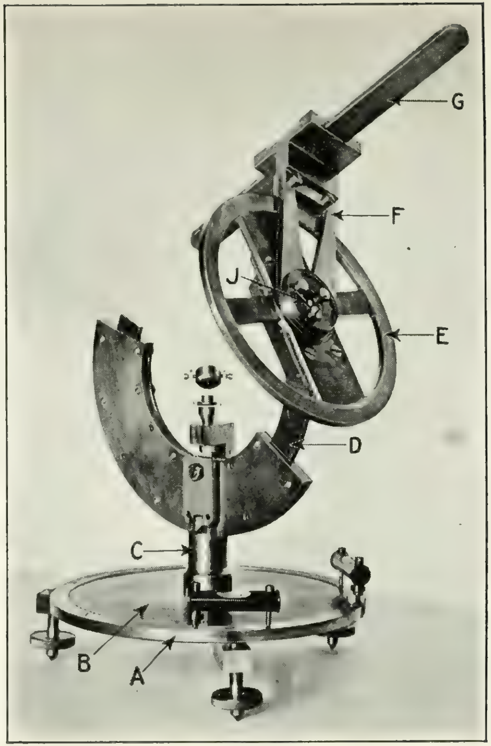


Fig. 10. New instrument for sunlight and shadow determinations.

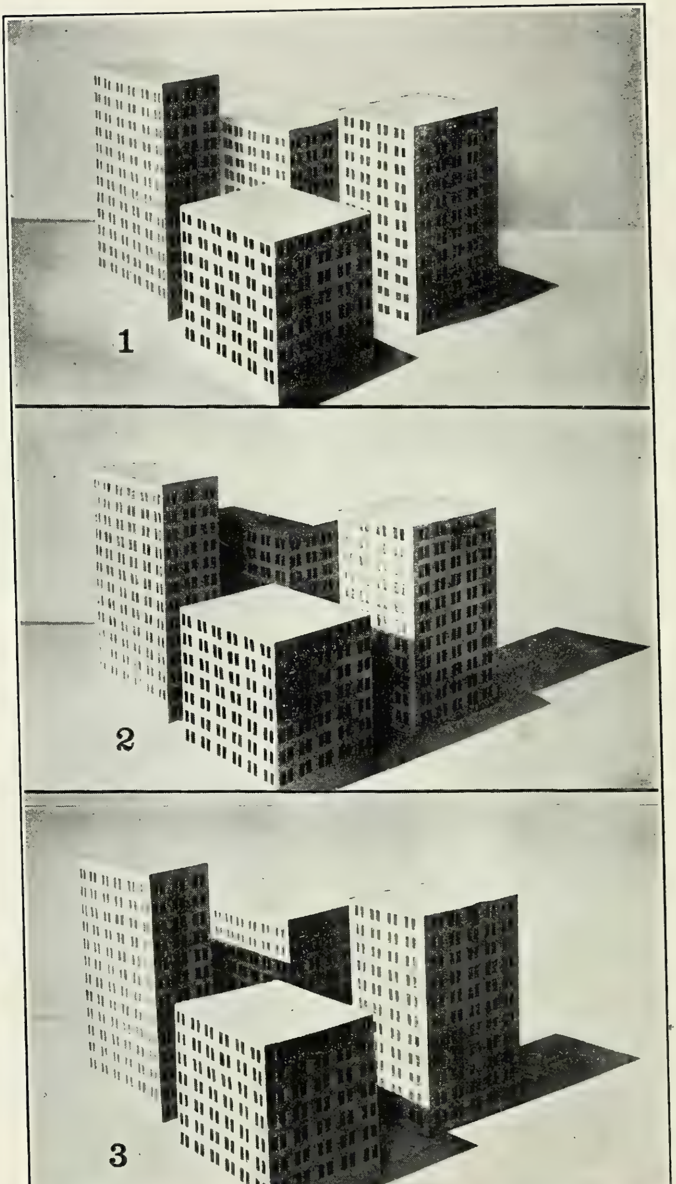


Fig. 11.—Cardboard models of buildings made to scale showing shadows at noon hour, (1) summer solstice, (2) winter solstice, (3) vernal and autumnal equinoxes.

of orientation with respect to the points of the compass, and the effect of the shadows at various times of the day may also be easily compared and studied, as well as the changes due to the variations of the path of the sun at the various seasons of the year. Even in the case of buildings of complicated shape, the shadows may be determined with sufficient exactness for all practical purposes for any time of the day and any time of the year and for any position of the building.

A New Instrument for Sunlight and Shadow Determination.—A new instrument designed by J. E. Woodwell for rapidly and accurately determining the apparent position of the sun at any hour of any day in the year is shown in two views in Fig. 10. This instrument is constructed in accordance with the same underlying principles as those that hold for the wire frame previously described, but it is adjustable for any latitude between the equator and 60 deg. north or south latitude, and also for any time of the year.

The instrument consists of a stationary base A carrying a horizontal or horizon circle B to set the instrument at any desired azimuth. The vertical post C carries a vertical support for the vertical circle D by which adjustments are made for any degree of latitude from the equator or zero to 60 deg. north or south latitude. Upon this adjustable vertical circle D a stationary circle E is so mounted that the axis of the latter passes through the axis of the vertical circle and the vertical axis of the horizontal or azimuth circle. This circle E serves as an hour circle, each hour being represented by 15 deg. intervals.

Settings for the different hours of the day are made by means of a revolving arm F. The revolving arm F carries with it a support for the adjustable sliding arm G, which has, at its inner end a small circular aperture through which a beam of light may be projected upon the crosshairs so mounted upon an adjustable support H that the center of the crosshairs lies at all times in the vertical axis of the horizon or azimuth circle B, the center of the vertical circle D and in the axis of the hour circle E.

The adjustable sliding arm G is set perpendicular to the plane of the hour circle and is calibrated to correspond with the set-

tings of the instrument for any day of the year. At the dates of the equinoxes, for example, the sliding arm G is so set that a beam of light received from an artificial light source so placed as to correspond with the direction of the sun, would pass through the circular aperture in the sliding arm G and intersect the crosshairs at the center of the instrument in a line parallel to the plane of the hour circle and perpendicular to the axis passing through the center of the hour circle and the center crosshairs set to represent the latitude of the place for which the instrument is adjusted.

Due to the inclination of the axis of the earth at 23½ deg. the settings for the summer and winter solstices are made by sliding the adjustable arm G towards or away from the hour circle an amount which is equivalent to the angular distance of 23½ deg. either side of the setting for the equinox. The settings for intermediate months and days of the year are made in a similar manner by reference to astronomical tables giving the declination of the sun at zenith, etc.

The instrument may be levelled by means of the adjusting screws and the levels mounted on the base at right angles to each other, and when the vertical circle is set for the equator or at zero, the intersection of a beam of light passing through the second circular aperture J and the crosshairs at the center of the vertical circle will be in the plane of the horizon. A point on the horizon may be established at any point of the compass by merely revolving the azimuth plate upon which the instrument is mounted.

As in the case of the wire frame previously described representing the celestial sphere, the best results in determining shadows upon small scale models of buildings, etc., are secured by using a miniature lamp and a small parabolic reflector, the artificial light source being placed at a sufficient distance away from the model in proportion to the size of the latter to avoid distortion due to non-parallelism of the rays of light. In practise it has been found that a distance of ten times the greatest dimension of the model is ample to secure accurate results.

This instrument may also be used to determine the form of shadows produced by rays of light from certain definite direc-

tions upon architectural moldings, cornices, relief work, and also for determining the angles at which direct reflection of light is produced in connection with problems in interior illumination.

The accompanying photograph, Fig. 11, shows the obscuration of the direct sunlight at different times of the year for a specific group of buildings by means of small card-board models of the buildings constructed to scale. (1) shows the obscuration of the direct sunlight and consequent shadows at noon at the summer solstice. (2) shows the shadows for the same group of buildings at noon at the winter solstice. (3) shows the shadows of the same group of buildings at the vernal and autumnal equinoxes. The shadows for any intermediate period may be similarly shown.

DAYLIGHTING FACILITIES OF NEW COURT HOUSE.

The new County Court House to be erected in New York City at an estimated cost of $10,000,000, presents unusual problems in daylighting owing to the architectural features of the building which was designed by Mr. Guy Lowell, architect.

The plans of the Court House show a circular building approximately 400 ft. (121.8 m.) in diameter and 200 ft. (60.9 m.) high containing an annular court or open space in ring form 40 ft. (12.2 m.) wide. This court is crossed by bridges connecting with the main building. The inner wall of this court rises 75 ft. (22.8 m.) above the floor line of the fourth floor. The following preliminary plans of the building are submitted in Fig. 3 and Appendices 7, 8 and 9: typical court room plan showing grouping of court rooms into separate units; section of building on north and south axis according to architect's plan No. 3; plan of typical court room corresponding to plan No. 3, showing windows and light court, arrangement of room and exterior columns; section of typical court rooms through fourth and fifth floors at colonnade, corresponding to plan No. 3.

Obstruction of Light by the Walls of the Annular Court.—The reduction of sky angle due to the obstruction of light by the walls of the annular court and by the connecting bridges shown in the preliminary plans submitted will result in cutting out a large percentage of the light that would otherwise reach the working portions of the court room through the rear windows on the

fourth and fifth floors. In view of the ample provision of light through the large windows in the outer wall, this reduction is not serious with respect to adequacy of lighting facilities but rather with respect to flexibility; that is to say dependence must be placed very largely on lighting from one side (the outside windows) only, as the light coming through the windows on the court side would not alone be sufficient to give adequate illumination of the room. The flexibility possible with equal lighting facilities on both sides of a room is often a great advantage, especially when the erection of high buildings close by and immediately opposite the windows results in obstructing the light on one side; and also when it becomes necessary to screen direct sunlight on one side during working hours.

Reduction of Light Due to Surrounding High Buildings.—From observations made on the site of the proposed new Court House at a height of 100 ft. (30.5 m.) above the ground (fourth floor court room level), it was found that at the present time there is substantially no sky obstruction at this level with the exception of that due to a few buildings on the south and west, the sky angle averaging approximately only 12 deg. A chart showing the sky angle at the fourth floor level for 360 deg. is given in Appendix 5.

The probable growth of tall buildings in the vicinity in the future will considerably reduce the effective daylight on the lower floors of the Court House.

The Effect of the Contour and Depth of Windows and of the Exterior Colonnade upon the Visual Angle.—What is sometimes termed the visual angle of the window is the angle between two planes that pass through the edges of the glass at the sides of the windows and the furthest projecting edge of the building wall or column, as the case may be. It is very important that the exterior colonnade be located close to the outer wall of the building as a very slight increase in the distance of the columns from the window wall results in a material decrease in the visual angle of the window, as may be readily seen from the diagram Fig. 7. Calculations show that the increase in the visual angle that would be obtained by the removal of the columns from the present location shown on the plans, would not secure a material

increase in effective daylight within the rooms. Hence from the lighting standpoint there is no need of sacrificing the exterior colonnade which may be said to constitute an indispensable element of beauty of the exterior.

The contour and depth of the windows as revealed in the plans are favorable to good lighting. On the fourth floor the projecting stone above the lower window will considerably obstruct the ingress of light through this window. However, since the main lighting of the room is carried out by the upper windows this obstruction will not reduce the total daylight in the room to any material extent.

Window Area and Visual Angle.—The ratio of the floor area to the glass area, and the visual angle taken 3 ft. (0.9 m.) above the floor at the wall opposite the windows in several court rooms in the present New York County Court House and in the principal court rooms of the new Court House are given in Appendix 10.

Daylight Illumination Measurements.—Measurements of daylight illumination were made in a test room to determine the actual intensity of daylight on the working plane at different times of day and on different days. Similar measurements were made in several court rooms of the present Court House. The rooms chosen are a court room said to be favored by several of the justices because it has windows on three sides, thus providing for better lighting and ventilation than in most of the other rooms; a court room having three windows on one side only; and a court room having two windows on one side only, chosen because both windows were exposed to direct sunlight. In the last of these, measurements were made when direct sunlight was shining into the room and also when the windows were screened by amber colored shades. The charts submitted contain the records of illumination tests in all these rooms (see Appendices 2 and 3).

Unilateral Lighting as Compared with Lighting from Two or More Sides.—In planning the lighting of school rooms there is a strong tendency towards the adoption of unilateral lighting, with windows located in the wall to the left of the pupils. When this plan is adopted it is desirable that the ceiling, and wall op-

posite the windows should be light in color to secure suitable diffusion of daylight. Calculations from the plans submitted for the Court House show that more than 90 per cent. of the light on the working spaces of the fourth floor court rooms will come from the three windows in the outside wall, as the two windows in the wall looking out on the annular court will receive very little direct light. On this floor therefore, if the present plan were followed, we would have a close approach to unilateral lighting. In fact the two windows in the court wall would probably not contribute as much to the effective lighting of the main portion of the room as would a wall placed in front of the wing to be used for a visitors' gallery. Such a wall (light in color) would considerably increase the diffused light in the room.

The chief advantage of the two windows on the court side of each room on the fourth floor would be from the standpoint of ventilation rather than that of lighting.

On the fifth floor more than 80 per cent. of the light on the working spaces would come from the three windows in the outside wall according to the present plan.

The typical court room shown on the plan has a wing containing the visitors' raised platform. The disposition of windows in this room is such as to secure adequate daylight and satisfactory ditribution of light, provided the walls and ceiling are made light in color and suitable means are employed for screening direct sunlight without darkening the room to a prohibitive degree. Although such means can be readily devised it is considered desirable to insure greater flexibility of lighting facilities on the fourth and fifth floors, by added lighting from the court side so as to permit of satisfactorily lighting the room mainly from either one side or the other, thus securing substantially all of the advantages of unilateral and of bilateral lighting.

Lighting from more than two sides is almost always open to serious objections.

In a city like New York, especially in lower Manhattan where high office buildings are likely to be built close together, the provision of a surplus of daylight from the open court of a large building would have the added advantage of compensating for

any obstruction of light by high buildings that may be erected in the vicinity in the future.

There is a great diversity of opinion as to the relative merits of unilateral, bilateral, and skylight lighting for different classes of interiors; except in the lighting of school rooms very little progress has been made towards standardization of methods of daylighting.

Effect of Color of Walls.—The color of walls and ceiling and also of room furnishings plays an important part in the distribution of daylight within the interior. A window area that would be adequate for the provision of good daylight within the room if the walls and ceiling are light in color, might be inadequate if the walls are dark in color. With unilateral lighting or with lighting that comes principally through windows located on one side of the room a light colored interior finish to secure good diffusion of light is a pre-requisite, because with dark walls there would be a marked tendency to strong contrast of light and shadow on the faces of those who do not face the windows—an objection which would have considerable weight in a court room.

Effect of Screening of Windows to Exclude Sunlight during Working Hours.—All of the court rooms are provided with windows on both sides; hence there will never be need of screening all of the windows to exclude direct sunlight. In the present plan, this flexibility of lighting facilities leaves little to be desired in the court rooms on the sixth floor, but is not secured on the fourth and fifth floors. However, with the proper use of suitable shades to screen the direct sunlight, good lighting conditions may be maintained on all of the court room floors.

A photometric test made in one of the court rooms lighted from one side only in the present County Court House Building, showed that when the windows were lighted by direct sunlight and the shades (amber colored) drawn to exclude the sunlight to the required degree, the occupants of the room still had sufficient light to carry on their work with comfort though the intensity of illumination was relatively low. The foot-candle intensities of daylight illumination in the court room under these conditions are given in Fig. 2, Appendix 3. It will be noted that on the judge's desk the intensity of daylight illumination was 2.75 foot-

candles (the minimum intensity in the working portions of the room). This intensity was considered quite sufficient for comfortable reading of law books and other papers before the court.

Penetration of Direct Sunlight.—A study was made of the exposure of the court rooms with reference to the penetration of direct sunlight at all times during the year; the calculations were checked by tests on a model of the building scaled according to plan 3. Sample charts containing information on which the periods of direct sunshine in the court rooms may be determined are shown in Appendix 6.

Based upon the preliminary design submitted, the tests and calculations show that a large percentage of the court rooms will receive direct sunlight on sunny days for at least an hour or two a day during the working term of the year. During the period from the late fall to the early spring there will be no substantial penetration of direct sunlight through the court room windows facing the court on the fourth floor, and for the same period five of the court rooms on this floor will receive no direct sunlight whatever during the working year.

APPENDIX I.

TABULATION OF BUILDING HEIGHT LIMITS IN AMERICAN AND EUROPEAN CITIES.

American Cities

Baltimore	175	feet
Boston[1]		
District A (Business and commercial)	125	"
District B (Residential section)	80–100	"
Buffalo[2]		
Charleston[1]	125	"
Chicago	200	"
Cleveland[1]	200	"
Erie[1]	200	"
Indianapolis	200	"
Los Angeles	150	"
Manchester, N. H	125	"
Milwaukee	225	"
New Orleans[1]	160	"
Portland, Ore	160	feet
Rochester[2]		
Scranton	125	"
Youngstown[1]		
Fort Wayne[1]	200	"
Providence	120	"
Salt Lake City	125	"
Toronto[3]	130	"
Washington D. C.		
Pennsylvania Ave	160	"
Business Sts[4]	130	"
Residence Sts[5]	85	"
Seattle ... about	20	stories

European Cities

Aix-la-Chapelle	65.6	feet
Altona	72.2	"
Berlin	72.2	"
Bremen	62.3	"
Breslau	72.2	"
Cologne	65.6	"
Dortmund	65.6	"
Dresden	72.2	"
Duisburg	65.6	"
Dusseldorf	65.6	"
Edinburgh	60.0	"
Elberfeld	65.6	"
Frankfort	65.6	"
Halle	59.0	"
Hamburg	78.7	"
Hanover	65.6	feet
Kiel	72.2	"
Leipzig	72.2	"
London	80.0	"
Lübeck	59.0	"
Magdeburg	65.6	"
Munich	72.2	"
Paris	65.6	"
Posen	65.6	"
Rome	78.5	"
Stockholm	72.2	"
Stuttgart	65.6	"
Vienna	82.0	"
Zurich	43.0	"

[1] Not to exceed 2½ times width of widest street.

[2] Not to exceed 4 times average least dimension.

[3] Not to exceed 5 times least dimension at base.

[4] Not to exceed street width plus 20 feet.

[5] An intermediate height between 60 feet and 85 feet on streets over 70 feet wide—height not to exceed width of street minus 10 feet; 60 feet on streets from 60 to 70 feet wide; and street width on streets less than 60 feet wide.

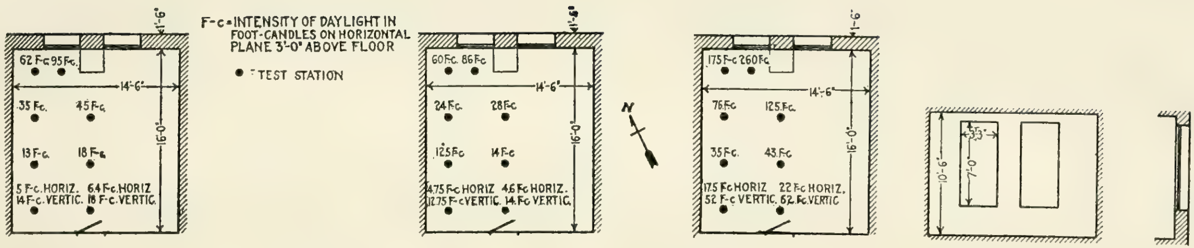
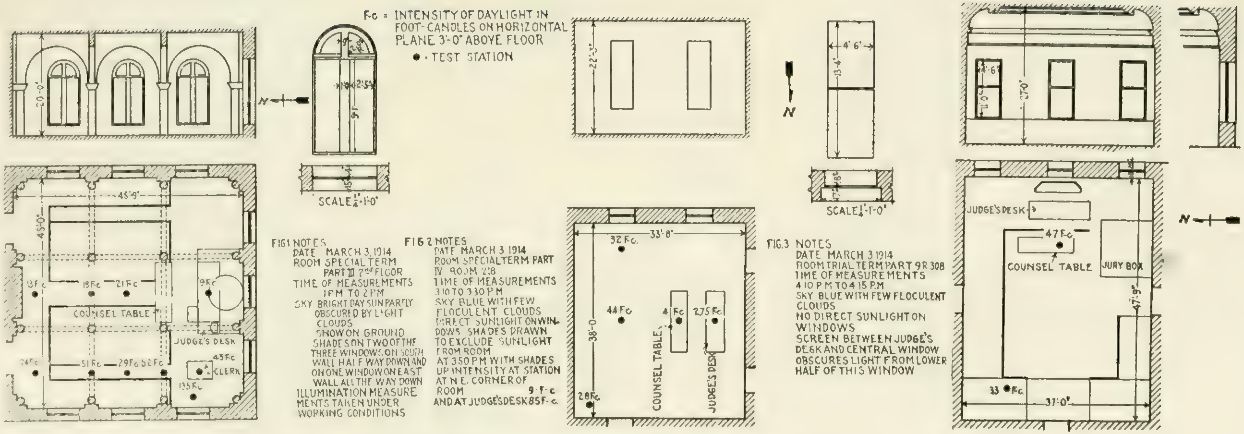


FIG. 1. NOTES:
DATE. FEB. 28, 1914
TIME OF MEASUREMENTS. 3.10 P.M. TO 3.45 P.M.
SKY. DULL GREY DAY
EXPOSURE. NORTH
PHOTOMETER. SHARP-MILLAR

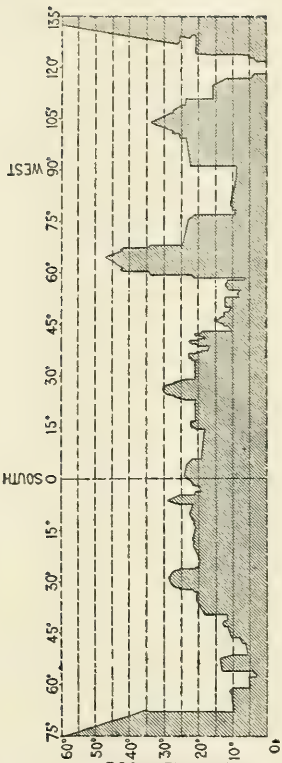
FIG. 2 NOTES:
DATE. MARCH 2, 1914.
TIME OF MEASUREMENTS. 3.10 P.M. TO 4.00 P.M.
SKY. DULL GREY DAY
ROOFTOPS AND STREET COVERED WITH SNOW
ILLUMINATION INTENSITY ON HORIZONTAL PLANE AT BASE OF WINDOW, INSIDE OF ROOM - - - - - 125 F-c
ILLUMINATION INTENSITY VERTICAL PLANE SAME LOCATION - - - - - 145 F-c
ILLUMINATION INTENSITY AT MOST FAVORABLE ANGLE - - - - - 200 F-c.

FIG. 3 NOTES:
DATE MARCH 4, 1914
TIME OF MEASUREMENTS 10 A.M. TO 11 A.M.
SKY BRIGHT DAY, SUN OBSCURED BY LIGHT CLOUDS.
SNOW ON STREET BUT NOT ON ROOF TOPS.
ILLUMINATION INTENSITY ON HORIZONTAL PLANE AT BASE OF WINDOW, INSIDE OF ROOM - - - - - 440 F-c
ILLUMINATION INTENSITY VERTICAL PLANE SAME LOCATION - - - - - 500 F-c
ILLUMINATION INTENSITY AT MOST FAVORABLE ANGLE, BEYOND THE RANGE OF PHOTOMETER

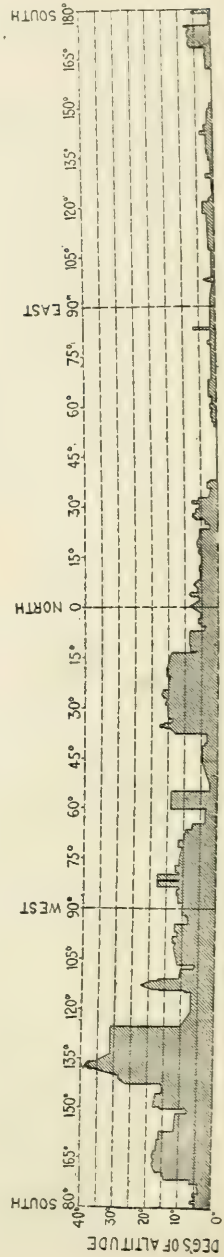
Appendix 2.—Measurements of daylight in test room.



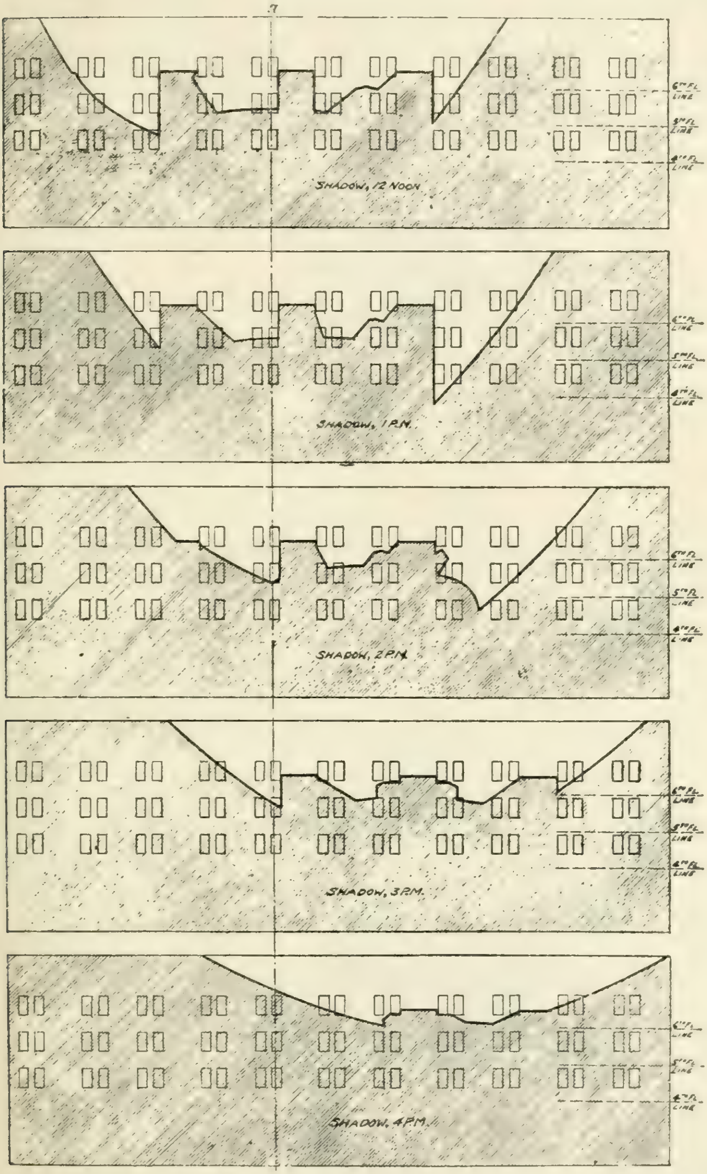
Appendix 3.—Measurements of daylight in court rooms.



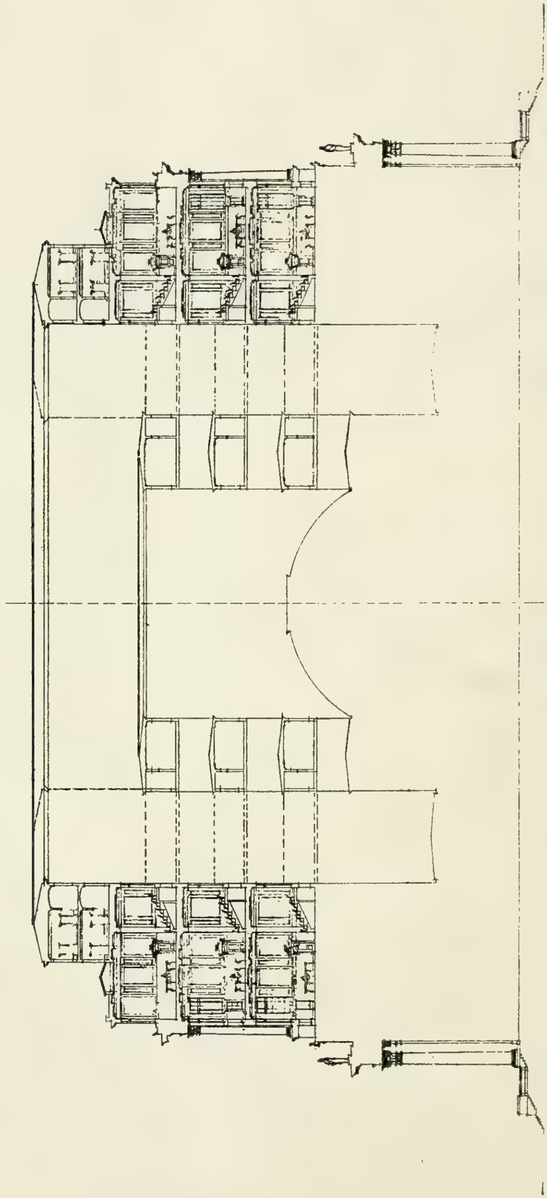
Appendix 4.—Sky line viewed from south wall of New York County Court House.



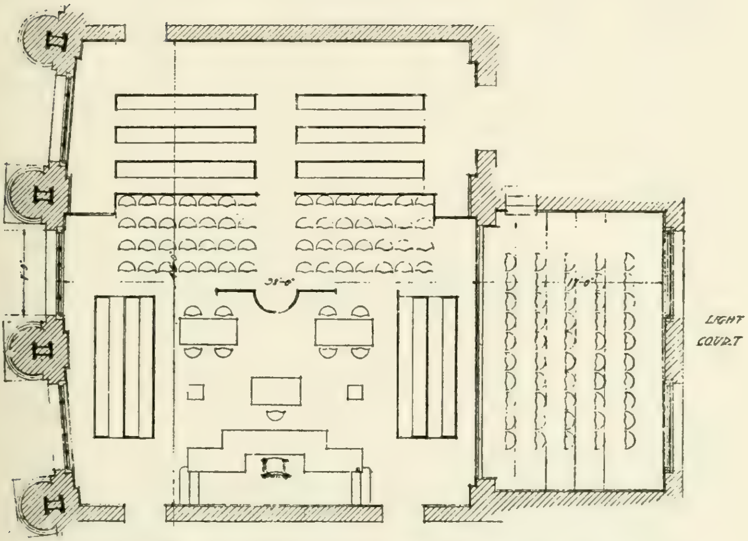
Appendix 5.—Sky line viewed from proposed site for new New York County Court House.



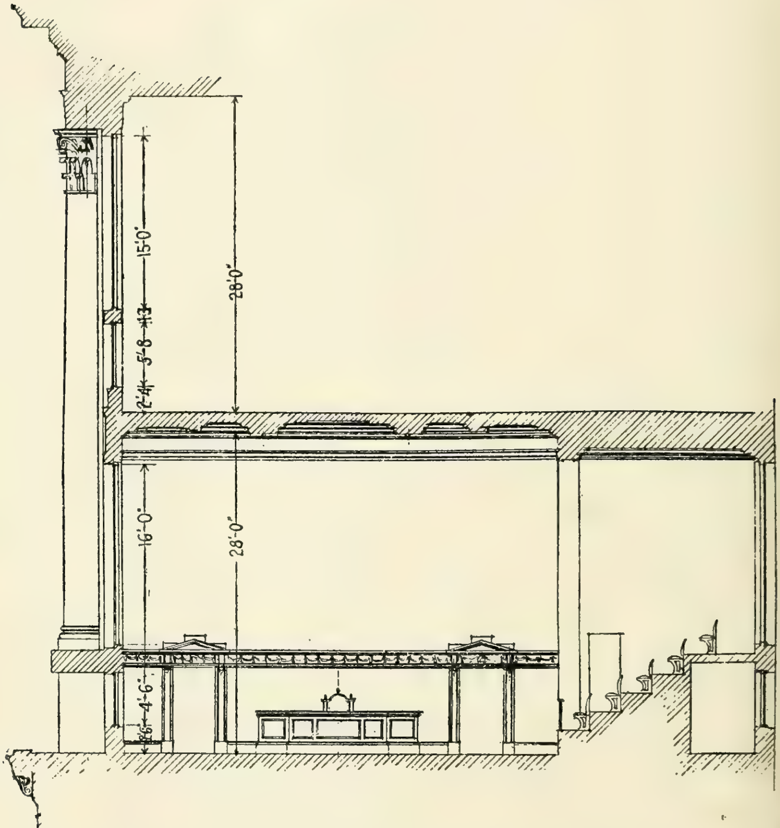
Appendix 6.—Shadows thrown on court room windows by the inner court and connecting bridges new New York County Court House, plotted for months of October and February. Shadows in morning hours similar to those in afternoon.



Appendix 7.—Section of building on north and south axis.



Appendix 8.—Plan of typical court room New York Court House.



Appendix 9.—Section through fourth and fifth floors at colonnade New York Court House.

APPENDIX 10.

COURT ROOM DATA.

I. Proposed new Court House, typical court room, as shown on plans.
II. Proposed new Court House, typical court room, assuming lighting from outside windows only and floor area limited to main room (exclusive of wing for visitors' platform).
III. Old New York County Court House.
IV. Test Room.

Court room type	Location	Floor area (sq. ft.)	Glass area (sq. ft.)	Ratio floor area to glass area	Visual angle[1]
I	5th floor	2,059	661	3.12 to 1	21° 45′
	4th floor	2,059	572	3.6 to 1	21° 45′
II	5th floor	1,639	428	3.82 to 1	27° 0′
	4th floor	1,639	339	4.83 to 1	30° 0′
III	2nd floor—				
	Special Term, Part 3,	2,060	451.5	4.56 to 1	15° 30′
	Special Term, Part 4, (Room 218)	1,279	120	10.67 to 1	24° 30′
	Trial Term, Part 9, (Room 308)	1,768	148.5	11.9 to 1	15° 45′
IV	Test Room	232	45.5	5.1 to 1	21° 45′

[1] Taken 3 feet (0.9 m.) above the floor at wall opposite windows.

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DISCUSSION.

Mr. S. G. Hibben: Not long since a resident owner called my attention to the fact that the front rooms of his home were in daytime the darkest ones in the house, notwithstanding the fact that these rooms were the most used and the most important. The darkness was caused there—and in fact will be caused in any average residence—by the shielding effect of a large porch, and overchanging eaves. This is a very common condition, and it seems peculiar to me that use has not been made of prism plate glass, or ribbed sheets, in the form of skylights set in the veranda roof, to direct the daylight against the face of the building and into the windows. Glass with a smooth upper side, and with prisms on its lower face, parallel to the building, would direct considerably more light into these front rooms than is found at present.

Going a little further, it seems reasonable to me that use could be made of translucent glass brick or glass blocks in the actual construction of a building. Such blocks could readily be made of a glass of pleasing color tints, impervious to weather, and it is conceivable how many beautiful effects could be worked into spaces between pilasters, around domes, friezes, etc. Many architects do not want to have the exterior of a building made characterless by the use of many windows. Glass brick, tinted the color of stone, would offer a solution of such a problem.

Mr. G. H. Stickney: While I have been interested mostly in artificial lighting problems, I feel we must recognize that it is inefficient to substitute artificial lighting where daylight is readily available. From my inspection of the lighting of a large number of buildings, I have had the feeling that architects in general were not giving as much care to the study of the daylighting problems, as well as the artificial lighting problems, as they deserved.

It would seem to me that this paper should be of special interest to architects, and an indication to them of the value of illuminating engineering study in connection with the design of buildings. There are many architects, on the other hand, who have made a thorough study of the lighting problems. I remember reading with interest and profit, the very extensive report of

the experiments carried on by Mr. McCormick, under Mr. Lowell's direction, for determining the design of the Museum of Fine Arts in Boston. I was surprised to find out how much attention had been given to the details of light projection, shadows and other lighting factors, in order to insure ample day illuminating in this remarkable building.

MR. WM. A. DURGIN: In educating ourselves to regular application of the new methods, which are so suggestively outlined, the instrument for sunlight and shadow determinations shown in the paper seems likely to prove a bit expensive for the earlier demands. Most testing engineers, I believe, will find that a little device, costing from $2.00 to $5.00 and known among amateur telescopists as a star finder, can be made to serve the principal uses of Mr. Woodwell's apparatus. Better yet, a small portable equatorial telescope may be borrowed in many localities from some embryo astronomer and in combination with a concentrated filament lamp can be arranged easily to give a parallel beam of light moving in paths duplicating the daily and seasonal cycles of change in sunlight direction.

DR. H. E. IVES: Of course we are all in unanimous agreement as to the tremendous value of this paper of Mr. Marks and Mr. Woodwell. I think it has been a matter of surprise to many of us to see how many different considerations have entered the problem—architectural, astronomical and even political.

It is perhaps ungenerous to suggest that the problem may become even more complicated, but I think it is the function of this Society to look ahead; we hope that this kind of work is going to be carried on by a great many of us and so we ought to be prepared for some of those other complexities. I want to deal with one of them for a minute. It has seemed to me that most of the papers we have read and seen quoted on daylight illumination have, to a striking degree, neglected the question of brightness. A great many of them have concealed in them some tacit assumption. Thus we have rules for window space in school rooms, but, as Mr. Marks has pointed out, it is assumed usually that the pupils all sit in a certain direction and that the teacher sits facing a certain direction; consequently a rule which is excellent for a school room would not be good for other places where

the seating is either not prescribed or is different. Now, to bring this matter to a very concrete instance, it makes all the difference in the world, no matter how a room is lighted, whether one faces east or west, whether one faces the light or faces the illuminated page, whether one wears an eye shade, whether one looks up or down; consequently I think that in a great many of the cases on which rules have been made, the really essential thing, the position of the observer or the worker, has either been tacitly assumed or left out; so that the conclusion, the formula, whatever is given, must be entirely altered. For instance, I notice that in some of these drawings of the court room, there are whole rows of people facing windows; the sky line has been treated here from the standpoint of illumination; the treatment would be very different from the standpoint of what these people are going to see. I remember last year it was my honor and responsibility to preside at a meeting of the International Congress on Social Hygiene, a joint meeting with this Society, in one of the court rooms that have been the subject of so much mention this morning. Seated on the too large and glorious throne of the Chief Justice, I faced the audience. The audience was magnificently illuminated and I was entirely comfortable. But the audience faced two large windows one on each side of the throne and I have never heard a greater concensus of opinion than that it was punishment to sit in that room. On the basis of illumination, going around with a test plate measuring at the seats, we would find that the window space, solid angles, and so on were splendid, but as a matter of fact with the way the majority of the people in that room faced, it was one of the worst possible arrangements that one could have.

I would like to call your attention to Fig. 6, and point out that the lengend Mr. Marks has put under that could be completely transformed from the standpoint of brightness considerations. As he has marked it, the tall, narrow window gives much better illumination that the broad low one. But consider the person sitting in the room who looks out of this tall window. Halfway up comes the skyline and above it is a patch of bright sky. The effect of this bright sky is to lower the efficiency of the observers vision even though the illumination in the room is higher. It can defeat

the very object for which it is intended. A low window on the other hand can be designed, and usually is, so that its upper part coincides with the sky line of the building opposite. The observer then does not have his visual efficiency depressed and the slightly low illumination is actually more useful. In fact the opposite legend could be put under this figure. A small analogy has occurred to me this morning, which I want to give slowly and leave with you: Is not designing a room on the basis of illumination equivalent to designing a room for blue printing? Is not designing on the basis of brightness, designing a room for photographing? If we have a large window space with plenty of sky, we are excellently situated for making blue prints, but if we want to photograph that side of the room, an expansive bright sky will solarize the plate and we will get nothing at all. The occupant of the room is a camera; he cannot face the bright sky space. The illumination photometer is a blue printing frame practically, and its record is a record of how good the illumination is for making blue prints. I think if you consider that, those of you who are going to devote more attention to daylight illumination as we all should, the importance of calculating what the occupants are going to see rather than the mere illumination, will come upon you.

MR. J. R. CRAVATH: The hygienic problems connected with artificial lighting, which we have been mostly considering heretofore, are largely those pertaining directly to the eye, whereas the hygienic problems of daylight involve not only the eye, but the general health, and germicidal effects. In arranging for daylight illumination, it is quite necessary, according to our present medical authorities, to provide for sunlight at various hours of the day, even if we shut off part of that sunlight during part of the day when we happen to be working in certain positions where it would annoy us.

In addition to the daylight illumination of our public buildings, I think it would be in order for us all to give a little more consideration than is commonly given to the daylight illumination of our homes. We see fine residences located in districts where there is opportunity for plenty of good, wholesome daylight, in which the windows are so shaded or so small or so ob-

structed by porches that we have very little good daylight entering the house.

Another thing I would like to call attention to is the tremendous variations in daylight, from hour to hour, during the same day in our large cities. We have daylight variations in our ordinary offices in Chicago, all the way from two and a half foot-candles up to a hundred on desks near windows. When it gets below two and a half, the user generally wants artificial light.

MR. J. B. TAYLOR: All buildings and especially large city buildings must be compromises. If a large number of court rooms are to be put under one roof, it appears at the outset more or less impossible to have ideal lighting conditions in all those rooms; but it does seem that the question of glare already brought out by Dr. Ives is extremely pertinent. He has referred to the plan of Fig. 6, but I wish to call your attention to the plan of Appendix 8 with the accompanying cross section of Appendix 9. While I have occupied several positions in a court room, I have not had the privilege of taking the throne of justice; in that respect Dr. Ives has the advantage of me—but it seems to me that this room is going to serve well, as far as the lighting goes, for all except those seated in what I take to be one of the jury boxes and those in one bank of seats who may be auditors, visitors or curiosity seekers. Now this last class of people perhaps can be more or less neglected in a court room because they are there only on tolerance. But besides the spectators compelled to face the windows, a jury in one of the boxes must fix their attention on counsel, witness, accused or exhibits in evidence appearing much as silhouettes against a bright sky back-ground. As Mr. Marks stated very clearly, the court room conditions and individual positions are by no means the same as in a theatre. On the stage the actors have to stand the glare of the footlights and do not complain of discomfort from the spotlight. In the court room it may be proper to regard judge and jury as holders of the best seats and after them the most desirable positions as far as comfort and ability to see and hear go, should taper down to the spectators,—as court rooms are constructed and as cases are conducted they can seldom be properly called auditors.

Mr. A. S. Osborn: As the result of my observations I have a feeling that to some extent we have all been imposed upon by the architects. I think that they have been influenced too much by a consideration of the building from the outside as affected by the size and location of the windows, and this is particularly true of our court rooms. This enormous great throne, that has been referred to, and the arrangement of the various elements in the court room has also been unduly influenced by the thought of appearance instead of efficiency. The windows should be designed not for the appearance of the building on the outside but for the convenience of those who are using it on the inside.

Dr. M. G. Lloyd: It seems to me that daylight illumination and avoidance of glare can be reconciled if proper attention is given by architects to the subject. I have in mind now a church building in Oak Park, Ill., which, from the outside, at first looks almost like a dungeon, that is, with apparently no windows. If one lifts the eyes a little, one sees that there are windows in the upper part of the building. One might think that this is a building where one would always have to use artificial light inside. It turns out, however, to be one of the best lighted and most comfortably lighted structures I have ever been in. The general arrangement is a not uncommon one of a large floor area with galleries around three sides, and the windows are entirely above the galleries, but, aided by a skylight, they throw enough light not only in the galleries but also down on the main floor for every purpose during the daytime. It is a fine example of utilizing daylight without any of the disadvantages that have been mentioned here this morning.

I want to register my disagreement with the authors in reference to the statements made in connection with Fig. 6. I do not think a general statement applying to all rooms can be made, and final judgment must depend upon room dimensions, etc., in any particular case. In a majority of cases, however, I believe better illumination conditions are secured by horizontal windows high in the wall. I surmise that the prevalent vertical window has been developed to meet two conditions not concerned with illumination; namely, architectural appearance, and convenience in looking out.

Mr. Norman Macbeth: The remark has been frequently made that the only thing wrong with daylight is that it is so cheap, and I think that a great many of us have overlooked the fact that artificial light is also very inexpensive. One or two experiences I have had along that line may illustrate my points, one having to do with the consideration the architect gives to daylight in a building.

I had a store to equip with artificial lighting. There were windows in front and rear and a skylight through part of the ceiling; outlets had been regularly provided down the center of the ceiling; then in an addition, near the center of the store, a section of an adjoining building had been taken. There were no windows in this section and although the width was the same as the main section, the architect had provided three outlets within a similar distance to a corresponding section in the main store where but two outlets had been provided. The explanation was to the effect that daylight was admitted to the main section whereas none could be counted upon in the small side section. On asking the question as to how much darker this small section would be at night than the main store, the fallacy of the idea was shown, resulting in a change of outlets in the small section to be uniform with the outlets throughout the entire floor.

Mr. Marks mentioned the meeting of the Heights of Buildings Commission. I remember very distinctly where that meeting was held on the 11th floor of a building down on Broadway, New York, and across the street from where the Equitable Building had stood. As a consequence on the 11th floor, the skyline was about level with the window sill. When we entered that room about three o'clock in the afternoon, the shades were all drawn and the artificial light was on. I asked the secretary why that was. He said, "I don't know." I then raised the shades and put out the lights, to note the relative conditions, and then drew down the blinds and put the lights on again. I checked up the size of the room and noted the kind and size of the units used in the room. When the members of the commission arrived and the discussion was under way, I raised this point. "Has it occurred to you that on this question of daylighting you are working here at three or four o'clock in the afternoon under

artificial light with all this beautiful sky out here and all the daylight you want?" Feeling there might be a suspicion that somebody had manipulated things, I suggested that the artificial lights be put out and the shades raised, then a vote be taken whether they wanted daylight or artificial light. This was done and decision favored the artificial light. The point I want to bring out is this; if it was decided in the congested sections of our large cities to pull down all our high buildings to 4 stories in order to have daylight, thousands of office workers in lower New York would have to go over to the marshes of New Jersey, because there wouldn't be room for them in New York. This would of course raise the rentals for this New York property enormously. The rental paid for the room where that meeting was held was $3.00 a square foot per year, and the lighting arrangements in that room, which were more satisfactory to the members of the commission and other workers in the room than the ample daylight available, was provided with an energy expenditure of 500 watts per hour for 1,200 square feet. They could use this artificial lighting in that room 10 hours a day 300 days in the year for 2 per cent. of the rental of that office, so that daylight is not always inexpensive nor is it always satisfactory. Artificial lighting can easily be provided which is satisfactory, and in our cities at any rate it is quite likely to be less expensive if not actually inexpensive.

Mr. L. B. Marks (In reply): In reference to Dr. Ives' discussion I may say that the fundamental problem treated in the paper is how to get *sufficient* light into the interior; the paper does not pretend to go into detail as to the interior arrangements best suited to secure the most advantageous distribution of the light that enters the windows. The factors governing the admission of daylight are treated in the paper under five headings, of which the "brightness of the sky" is one. If we could count upon a high value of sky brightness every day and all day we would make very radical changes in the present methods of planning window openings in buildings; but the practical design of window openings must take into consideration the supply of sufficient daylight with the low degree of sky brightness which obtains for a large portion of the working year.

As has been pointed out, it is desirable that the interior arrangements be such that no one is compelled to face a window or indeed any very bright surface. This seems almost self-evident; but in a court room in which each of the four sides must be faced by some of the occupants or by others, the practical problem sifts itself down to minimizing the effect of glare from the windows. Dr. Ives has apparently misinterpreted the drawings of the court rooms as the interior arrangements are purposely such as to avoid facing the windows, the bulk of the light coming from the windows on one side only. The windows on the other side of the room open on an interior court and are located above a raised platform used as a supplementary visitors' gallery; except on the top floor these windows contribute only a small portion of the room lighting, one of their functions being to permit of cross currents of air for purposes of ventilation.

With regard to the ratio of window area to floor area which is often taken as a criterion in planning window openings, the paper points out that this ratio may be meaningless and even misleading unless other factors cited in the paper, such as the visual angle, etc., are taken into consideration. Fig. 6 to which criticism has been directed in the discussion, brings out this point clearly by showing two windows of equal area, one vertical and the other horizontal. The authors did not suspect for a moment that anyone who had studied the problem of daylighting would question the superiority of the vertical window to the horizontal window under every-day conditions of practical daylighting in buildings. The fact is that even with vertical windows structural conditions and interior arrangements are such, especially in cities where buildings must necessarily be close together and several stories high, that it is often impossible to get sufficient daylight into the rooms. This is notably so in many office buildings where artificial light is required in some portions of the rooms even on bright days. Simple calculation will show that under these conditions the horizontal window would in most cases be a hopelessly impracticable proposition. Furthermore in the discussion relating to this phase of the subject the importance of admission of direct sunlight for hygienic reasons seems to have been overlooked and in this respect the advantage of the vertical window must certainly be apparent.

In what precedes I have been discussing practical conditions and practical limitations that exist in planning for daylight and sunlight in buildings. There are of course isolated cases and many of them that are exceptions to the rule, as for example, buildings provided with skylights and buildings having a superabundance of daylight available from side windows.

The first consideration in every case should be manifestly the provision of sufficient window openings to secure adequate penetration of light; after that come questions of brightness, diffusion of light, wall color, etc. In the control of the light incident at the window the provision of suitable shades goes far towards meeting the situation with respect to glare from the sky or from sun-lit buildings opposite.

With regard to the use of the star finder for making sunlight and shadow determinations or the more expensive and elaborate telescope with the requisite astronomical tables, it would appear that in the solution of the problems we have to consider, a specially designed and calibrated instrument which is complete in itself and may be used directly without any tables whatever, would best serve the purpose. For approximate determinations the wire frame described in the paper seems about as simple a device as could be used.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 7, 1914

PART II

Miscellaneous Notes

Council Notes.

The first regular meeting of the ouncil of the year 1914-15 was held ctober 8 in the general offices of the ociety, 29 West 39th Street, New York, . Y. Those present were: C. O. ond, H. Calvert, Joseph D. Israel, . A. Littlefield, L. B. Marks, A. S. [cAllister, president; Preston S. Millar, Arnold Norcross, C. J. Russell and . H. Stickney.

The minutes of the June meeting as ad were adopted.

The Council Executive Committee esented the following report giving a mmary of its activities on behalf of e Council during the summer months:

Since the last meeting of the Council in June, e Council Executive Committee has:

(1) Held three meetings, July 23, August 27, ptember 3, 1914.

(2) Authorized the payment of vouchers No. 62 to No. 1824 inclusive, aggregating $1,961.90.

(3) Elected fifteen applicants for individual embership, and one for sustaining memberip.

(4) Accepted the resignations of six members.

(5) Confirmed various committee appointents.

(6) Appointed P. W. Cobb (chairman), P. G. utting and J. R. Cravath a committee to -operate with a committee of the American phthalmological Society on the standardization the illumination of ocular test types. The ame of the committee is to announced later.

The report was adopted.

A special meeting of the Council was eld in the Hollenden Hotel, Cleveland, hio, September 22, 1914. Those esent were C. O. Bond, president; R. Cravath, Ward Harrison, Joseph . Israel, L. B. Marks, and G. H. ickney. The only business transacted s the appointment of a special comttee of five members to arrange for annual meeting of the Society tober 8, 1914.

The foregoing minute was adopted.

It was voted that a resolution of thanks be sent to the chairman of each committee and section, for services rendered during the preceding administration.

A draft of the annual report of the Council to the Society was prepared for presentation at the annual meeting, October 8, 1914.

Upon recommendation of the Finance Committee, payment of vouchers No. 1825 to No. 1866 inclusive was authorized.

Reports on section activities were made by Mr. G. H. Stickney, vice-president of the New York Section, and Mr. H. Calvert for Mr. Geo. A. Hoadley, vice-president of the Philadelphia Section.

It was resolved that a vote of thanks be tendered to retiring President C. O. Bond, whose praiseworthy services have been an inspiration in the work of the Society during the past year.

The resignation of Mr. Joseph D. Israel as general secretary of the Society was accepted with regret and a vote of thanks extended for services rendered.

Mr. C. A. Littlefield was appointed general secretary to succeed Mr. Joseph D. Israel.

Mr. Littlefield's resignation as a director of the Society was accepted.

Mr. Joseph D. Israel was appointed director to succeed Mr. C. A. Littlefield as director.

The resignation of Mr. V. R. Lansingh, director, was accepted. Whereupon a special committee consisting of Messrs. C. O. Bond, L. B. Marks, and Preston S. Millar presented the following resolutions which were adopted:

WHEREAS, Mr. Van Rensselaer Lansingh, one of the founders of the Illuminating Engineering Society, has served the Society continuously and faithfully from the date of its organization, hold-

ing at different times the offices of director secretary, treasurer, vice-president and president, as well as the chairmanship of important committees, and

WHEREAS, circumstances have in his judgment made imperative his withdrawal from the Council and from active work in the Society, therefore,

Be it Resolved, That the Council, in regretfully acceding to his wishes, does on behalf of the membership of the Illuminating Engineering Society express its thorough appreciation of his pioneer work in spreading the principles of proper lighting in this country, and hereby tenders to him a hearty vote of thanks for his valuable services to this Society.

Be it Further Resolved, That this action be noted in the minutes of the Society and that an engrossed copy of the resolution be sent to Mr. Lansingh.

The following committee appointments were confirmed:

Committee on Nomenclature and Standards: A. E. Kennelly, chairman; C. H. Sharp, secretary; Louis Bell, C. O. Bond, S. E. Doane, E. P. Hyde, C. O. Mailloux, A. S. Miller, E. B. Rosa.

Lighting Legislation Committee: L. B. Marks, chairman; O. H. Basquin, C. E. Clewell, Oscar H. Fogg, Herbert E. Ives, Clarence L. Law, F. J. Miller, G. H. Stickney, L. A. Tanzer, W. H. Tolman.

Papers Committee: G. H. Stickney, chairman; G. S. Barrows, E. J. Edwards, R. B. Ely, M. G. Lloyd, Norman Macdonald, C. E. Stephens.

Committee on Glare: P. G. Nutting, chairman; Nelson M. Black, J. R. Cravath, F. H. Gilpin, M. Luckiesh, F. K. Richtmyer, F. A. Vaughn.

Committee on Editing and Publication: C. H. Sharp, chairman; M. G. Lloyd, Norman Macbeth.

Advertising Committee: M. C. Turpin, chairman; J. Robert Crouse, B. F. Fisher, Jr., F. H. Gale, Joseph D. Israel, J. C. McQuiston, R. F. Pierce, F. J. Rutledge.

Sustaining Membership Committ Preston S. Millar, chairman; W. Skiff, E. W. Lloyd, D. McFarlan Mo R. F. Pierce.

Committee on Membership: McFarlan Moore, chairman; A. Abbott, J. J. Burns, Chas. M. C W. R. Collier, H. E. H. Grant, W. Kilmer, Harold Kirschberg, H. McLean, P. S. Millar, C. H. Mc F. H. Murphy, F. A. Osborn, C. Ramsburg, S. L. E. Rose, E. B. Ro Albert Scheible, Samuel Snyder, G. Shepardson, G. E. Williamson, A. Wilson.

Committee on Reciprocal Relati with Other Societies: Wm. J. Ser chairman; Bassett Jones, Jr., F. P Lewis, C. J. Mundo, C. J. Russ Stephen A. Thomas, Frank E. Wallis

Board of Examiners: W. Cul Morris, chairman; Bassett Jones, Jr.

Exhibition Booth Committee (Ga Oscar H. Fogg, chairman; G. S. B rows, W. F. Little.

Exhibition Booth Committee (El tric): Ward Harrison, chairman; W. Bettcher, N. H. Boynton, W. Little.

Finance Committee: A. Hertz, cha man; Joseph D. Israel, J. Arnold N cross.

A communication from the Americ Medical Association on street car lig ing was referred to Mr. W. J. Serr chairman, Committee on Reciprocal F lations with Other Societies, for reco mendations.

A communication from Mr. W. Serrill enclosing a letter from the M waukee Section of the American In tute of Electrical Engineers suggest a joint meeting with the I. E. S. street lighting was received. The s retary was directed to ask Mr. Ser

reply to the letter stating that the uncil thinks that the time is not portune for the holding of such a eting.

Section Activities.

CHICAGO SECTION

The first meeting of the season 1914-15 was held at the Grand Pacific otel, October 22. Mr. W. A. Durgin, airman, gave a brief history of illuminating engineering and outlined a tentae program for the year. Synopses a number of the papers presented at e Cleveland Convention of the Society September were given by Messrs. O. Dicker, J. R. Cravath and M. G. oyd. Twenty-two members and guests ere present.

The tentative program of papers for e Chicago Section for the season 1914-15 is as follows:

November—Physical Light.

December—The Eye: Physiology of ght. Psychology of Seeing.

January—Incandescent Light Sources Gas and Electric).

February—Other Light Sources (Gas id Electric).

March—Decoration: Color Schemes; xture Forms; Use of Colored Sources.

April—Lighting of Small Interiors: omes; Small Offices; Show Windows.

May—Lighting of Large Interiors: urches; Halls; Large Offices.

une—Lighting of Open Air Spaces: eets; Building Exteriors; Signs.

NEW ENGLAND SECTION

he first meeting of the New England tion was held November 10, 1914, in Edison Building, Boston. Dr. A. E. nelly of Harvard University and ssrs. L. C. Porter and P. S. Bailey he General Electric Company presented papers on the subject "Searchlights and Headlights." The papers were supplemented by stereopticon and practical demonstrations, special reference being made to the new concentrated filament gas-filled incandescent lamps.

NEW YORK SECTION

At a meeting of the New York Section, held October 8, 1914, in the Engineering Societies Building the Cleveland Convention papers were reviewed by Mr. E. R. Treverton and discussed by Messrs. Bond, Stickney, Taylor, Serrill, Dr. McAllister and Norman Macbeth. Ninety members and guests were present. The usual informal dinner at Keen's Chop House, 39 West 36th Street, preceded the meeting.

PHILADELPHIA SECTION

The following papers were presented at a meeting of the Philadelphia Section held October 16, 1914, in the Meter Department of the Philadelphia Electric Company: "The Practical and Commercial Value of Illuminating Engineering as Viewed by Commercial Men," by Mr. Joseph Israel; "Light from 500,000 Volts," by Mr. L. C. Smith. A review of the Cleveland Convention paper was given by Messrs. G. Bertram Regar and H. Calvert. An informal dinner at the Engineers' Club preceded the meeting.

The program for the Philadelphia Section for the season 1914-1915 is as follows:

November 7—Joint meeting of the Engineers Club and the Illuminating Engineering Society. Lecture: "Physical Photometry," by Herbert E. Ives. Dr. Ives will exhibit apparatus in connection with his lecture.

November 20—"Light as Utilized for Lighthouse Purposes" by Raymond Haskell. This paper will be illustrated by lantern slides. "Lights and Light-

houses of the Delaware River and the Atlantic Coast" by Christopher S. Street. Navigation lanterns and lamps will be exhibited.

December 18—"Recent Developments in Gas Lighting" by T. J. Litle, Jr.; "New Methods and Devices in the Control and Distribution of Electric Lighting Installations" by Washington Devereux. Gas lamps and electrical control devices will be exhibited.

January 15—"Amusement Park Lighting—Lighting of Willow Grove Park" by Mr. Harry Markle; "Piping Houses for Gas Lighting" by H. R. Sterrett.

February 8—Joint meeting with American Institute of Electrical Engineers. "A Year's Progress in Illumination" by Prof. Geo. A. Hoadley; "Recent Developments and Applications of Incandescent Lamps" by Geo. H. Stickney. Electric lamps will be exhibited.

February 19—"Scientific Management" by Frederick W. Taylor. A demonstration of the pathescope, a new moving picture device, will be given.

March 19—"A Method of Securing Uniformity of Reading of the Flicker Photometer with Different Observers" by Herbert E. Ives and E. F. Kingsbury. Photometric apparatus will be exhibited.

April 16—"The Problem of Lighting Design." Methods used for designing: A. Direct Lighting. B. Indirect Lighting. Difficulties and faults in the use of such methods. Accuracy to be expected in the results accomplished. What constitutes good design. By Prof. Arthur J. Rowland. Exhibition of new types of lighting fixtures.

May 21—"Store Lighting" by W. R. Moulton. This meeting will be held in Baltimore, Md. The place will be announced later.

PITTSBURGH SECTION

A meeting of the Pittsburgh Section was held October 23, 1914, in the Auditorium of the Engineers Society of Western Pennsylvania. After the new officers were introduced and a brief outline of section plans presented, several of the Cleveland Convention papers were abstracted and discussed by Messrs. L. O. Grondahl, Harold Kirschberg, H. O. Swoboda, and J. L. Minick.

An interesting display of colored silks and fabrics under tungsten and artificial daylight illumination was arranged through the efforts of the Exhibition Committee and the courtesy of the McCreery & Company's Department Store.

The tentative program for the Pittsburgh Section for the season 1914-1915 is as follows:

December 18—"Modern Units for Street Lighting."

January—A joint meeting with several engineering societies, and a popular lecture and demonstration of school lighting and optical hygiene. This meeting will be held in Cleveland, O. The date will be announced later.

February—To be announced later.

March—Joint meeting with the American Institute of Electrical Engineers. Paper: "Headlights and Projections" or "Modern Lamp Manufacture."

New Members.

The following applicants have been elected members of the Society:

BEIL, E. H.
Manager Light and Power, Mahoning & Shenango Rwy. & Light Co., 25 E. Boardman St., Youngstown, Ohio. Elected October 8, 1914.

BENNETT, EDWARD.
Professor of Electrical Engineering, University of Wisconsin, Electrical Laboratory, Madison, Wis. Elected July 23, 1914.

BOCK, JOHN E.
Designer, General Electric Co., Illuminating Engineering Laboratory, Schenectady, N. Y. Elected July 23, 1914.

BOYCE, ERNEST WALTON.
Proprietor, New York Electric Lamp Co., 38 Park Row, New York, N. Y. Elected July 23, 1914.

BREWSTER, WILLIAM E.
Engineering Department, National Lamp Works, Nela Park, Cleveland, Ohio. Elected October 8, 1914.

CAMPBELL, GUY.
Managing Director, The Benjamin Electric, Ltd., La Rosebery Ave., London, E. C., England. Elected August 27, 1914.

CROOKER, ALFRED C.
Merchant, The Crooker Co., 230-232 Weybosset St., Providence, R. I. Elected September 3, 1914.

DOWS, CHESTER L.
Engineering Department, National Lamp Works, Cleveland, Ohio. Elected October 8, 1914.

GILLINGHAM, H. D.
New Business Assistant to Agent, Public Service Gas Co., 759 Broad St., Newark, N. J. Elected October 8, 1914.

GRAVES, R. EARLE.
Illuminating Engineer, Edison Sault Electric Co., 110 Askmun St., Sault Ste. Marie, Mich. Elected October 8, 1914.

HAFNER, W. J.
Salesman, Commonwealth Edison Co., 120 W. Adams St., Chicago, Ill. Elected August 27, 1914.

HEYBURN, HENRY B.
Illuminating Engineer, Belknop Hdw. & Mfg. Co., N. E. Cor. 1st and Washington Sts., Louisville, Ky. Elected July 23, 1914.

HODGE, WILLIAM E.
Deputy Supt. of Street Lighting for Springfield, City Hall, Springfield, Mass. Elected August 27, 1914.

HUTCHINSON, F. R.
Special Agent, The East Ohio Gas Co., 1447 E. 6th St., Cleveland, Ohio. Elected August 27, 1914.

KOCH, PAUL W.
Sales Engineer, Thos. G. Grier Co., 627 W. Jackson Blvd., Chicago, Ill. Elected July 23, 1914.

MAY, GEO. O.
Secretary, Electric Supply Co., 525 Fifth St., Sioux City, Ia. Elected July 23, 1914.

MOORE, WILLIAM CABLER.
Research Chemist, National Carbon Co., Cleveland, Ohio. Elected October 8, 1914.

MORTON, A. A.
Detail and Supply Dept., Westinghouse Electric & Mfg. Co., Union Bank Bldg., Pittsburgh, Pa. Elected October 8, 1914.

PRIEST, IRWIN G.
Assistant Physicist, National Bureau of Standards, Washington, D. C. Elected October 8, 1914.

SCHANZE, H. C., JR.
Secretary and Assistant Treasurer, The Coast Gas Co., 709 Ninth Ave., Belmar, N. J. Elected August 27, 1914.

SCHROEDER, P. A.
General Manager, Henry Newgard Co., 276 W. Water St., Milwaukee, Wis. Elected August 27, 1914.

SHIKATA, K.
Engineer, The Tokyo Electric Co., Kawasaki, Kanagawaken, Japan. Elected October 8, 1914.

SKOGLAND, J. F.
Assistant Physicist, Bureau of Standards, Washington, D. C. Elected October 8, 1914.

STEVENS, M. P.
Manager, Edward Schroeder Lamp Works, 716 Jersey Ave., Jersey City, N. J. Elected October 8, 1914.

TATUM, LEWIS L.
Assistant Chief Engineer, Cutler-Hammer Mfg. Co., Milwaukee, Wis. Elected August 27, 1914.

WEINTRAUB, EZECHIEL.
Director Research Laboratory, General Electric Co., Lynn, Mass. Elected October 8, 1914.

Sustaining Membership.

At a meeting of the Council held July 23, 1914, The New York Association for the Blind, 111 East 59th Street, New York, N. Y., was elected a sustaining member of the Society.

Annual Meeting.

The annual meeting of the Society was held in the Engineering Societies Building, October 8, 1914. The annual report of the Council was read by Mr. J. D. Israel. Mr. C. O. Bond, past-president, made a brief address outlining what the Society had done in the past year to diffuse knowledge relating to the principles of good lighting. He solicited the co-operation of the members for the new administration. He then introduced President A. S. McAllister, who outlined a policy for the year advocating wide publicity for the Society, and a hearty co-operation with all individuals and societies interested in the subject of illumination. Dr. McAllister also asked for the assistance of the members to increase the membership of the Society.

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THE COLOR OF ILLUMINANTS.*

BY L. A. JONES.

Synopsis: Color determination in dominant hue and purity have been made on a number of reproducible sources. The variations in hue and purity of the carbon lamp, the Nernst, ordinary tungsten and nitrogen-filled tungsten lamps have been studied over a wide range of efficiencies. Data are given for rapidly standardizing these lamps by color with a colorimeter.

Color analyses of the light emitted by various sources have been made by Ives[1] and others. In most cases these analyses have been made by the trichromatic method, involving the use of three arbitrary color screens, one red, one green and one blue. In this method a color is specified by giving the ratio of the intensities of the three beams transmitted by the color screens, which, when mixed together, will match the color of the unknown.

The monochromatic method of color analysis defines a color in terms of the wave-length of the dominant hue and the per cent. white, neither of which involve the use of any arbitrary reference standards. A colorimeter of the monochromatic type designed by Dr. P. G. Nutting[2] was used in making the analyses given in this paper.

The principle involved in the monochromatic method is that any color can be matched by the mixture, in proper proportions, of white light with monochromatic light of the required wave-

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

Communication No. 14 from the Research Laboratory of the Eastman Kodak Co.

[1] Ives, H. E.; TRANS. I. E. S., April, 1910, p. 206.

[2] Nutting, P. G.; *Bull. Bu. Standards*, Paper No. 187.

length. The wave-length of the monochromatic light that is necessary to make the color match is known as the wave-length of the dominant hue. The intensity of the white light expressed as a percentage of the sum of the intensities of the pure hue and white mixed together to match the color being analyzed is known as the "per cent. white."

In case the color being analyzed is a purple, that is, a mixture of red and blue, it is necessary to mix a pure hue of a definite wave-length with the unknown so that the resultant mixture matches white. This is the only exception to the general rule as previously stated, and the color specified in this case by giving the wave-length of that hue which mixed with the unknown will make white, and the intensity of the pure hue expressed as a percentage of the intensity of the mixture.

The analysis of color by this method requires the use of white light and hence it is necessary to define the quality of the light to be used as standard white. Several standards of white have been proposed such as a black body radiator[3] at 5,000° C. and the white as proposed by Nichols.[4] However, it seems much more logical to define standard white as the light from the noon sun. Observations extending over a considerable period of time show that no measurable variations in the color of sunlight occur between 9 A. M. and 3 P. M. In making the color analyses given in this paper, direct sunlight reflected from a non-selective surface, magnesium carbonate, was used as standard white.

In Fig. 1 is given a diagram showing the arrangement of the Nutting colorimeter as used in this investigation. A beam of sunlight, A, was thrown by a heliostat upon a block of magnesium carbonate, M_1. This was used as standard white light, and entered the instrument through the pair of nicol prisms, N_2, by means of which the intensity of the beam could be controlled. This beam, 2, then passed through the collimating lens L_2 was partially reflected at the surface of the glass plate C and illuminated the central portion of the field, *b*, Fig. 1a, of the Lummer-Brodhun cube D. The image of a Nernst glower, S_1, was formed by means of a condensing lens, F, on the slit B. This beam, 1, after passing through collimating lens L, was dispersed by the

[3] Ives, H. E.; TRANS. I. E. S., April, 1910.

[4] Nichols, E. L.; TRANS. I. E. S., May, 1908.

constant deviation prism E, and illuminated the field, *b*, Fig. 1a, with monochromatic light. The wave-length of this light was adjusted by rotating the drum H, which was graduated to read directly in wave-lengths. Thus it will be seen that the field *b* could be illuminated by a mixture of standard white and a pure hue and that the ratio of the intensities of the two components of this mixture could be adjusted to any desired value by rotating nicols in N_1 and N_2. Light (from S_2) of which the color was to be determined was introduced through N_3 and illuminated uniformly the fields, c, c^1. The intensity of this beam was adjusted

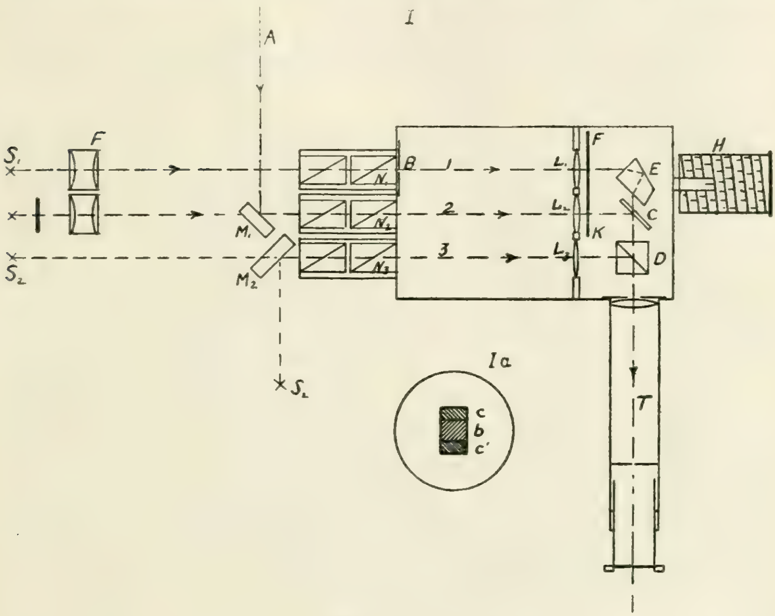

Fig. 1.—Diagram of colorimeter.

by rotating the nicol in N_3. In some cases the light to be analyzed was projected onto a block of magnesium carbonate M_2 placed in front of N_3 and in others an image of the source was formed by a condensing lens directly upon N_3. The magnesium carbonate is so nearly non-selective that no difference could be detected between the two methods.

The fields as shown in Fig. 1a were viewed by means of the telescope T, fitted with a pin-hole ocular. The photometer cube

D was of a type specially designed for this instrument and is particularly well adapted for making a precise color match. In making a setting with this field the attention is at first confined to the dividing line between *b* and *c*, and by adjusting the intensities of the beams 2 and 3 and the wave-length of the pure hue, the color match is made as precisely as possible. Then the attention is shifted to the line between *b* and c^1 when any lack of exact matching will become much more apparent than at the line between *b* and *c*. In this way the fatigue effect in the retina of the observer's eye is utilized to increase the precision in matching the unknown color with the mixture of white and a pure hue.

After a color match was made the wave-length of the pure hue was read from the drum H and the setting T*h* of the nicol in N_1 was recorded.

The next step in the making of an analysis was to determine the ratio of the intensity of the pure hue to that of the standard white. For this purpose a thin metal plate, FK, was provided, of such a shape that when placed in position it cut off the upper half of beam 1 and the lower half of 2. Thus the upper half of the field *b*, Fig. 1a, was illuminated by standard white and the lower half by the pure hue. Then by rotating the nicol in N_1, without moving the nicol in N_2 from the position it occupied where the color match was made, an intensity match between the two halves of *b* was obtained and the reading T*w* of the scale attached to the nicol N_1 was recorded. While making this intensity match beam S was cut off. From the readings thus obtained, T*w* and T*h*, the per cent. white was computed. The per cent. white, W, was computed by the formula—

$$W = \frac{Tw \,.\, 100}{Tw + T_H}\,.$$

In Table I are given the color analyses of light from various sources. In case of the flame sources such as pentane, Hefner, etc., there was some variation in color depending upon the region of the flame examined. In these cases the source was so placed that the field in the colorimeter was illuminated by light coming from that portion which was most uniform in color and of greatest intensity. The values given therefore apply to the most intense portion of the flame sources.

The helium tube used was of the type proposed by Dr. Nutting[5] as a primary standard light source and was operated on a current of about 25 mil-amperes.

The neon tube was of the same type.

The arc lamp used was a small automatic "Werle," taking 5 mm. cored carbons. The apparatus was so adjusted that the light from the flame was excluded and only that coming from the crater itself was used for the analysis. The results show only a slight change of color with change in current.

TABLE I.

Source	Color: Per cent. white	Color: Hue
1. Sunlight	100	—
2. Average clear sky	60	472.0
3. Standard candle	13	593.0
4. Hefner lamp	14	593.0
5. Pentane lamp	15	592.0
6. Tungsten glow lamp at 1.25 w. p. c.	35	588.0
7. Carbon glow lamp at 3.8 w. p. c.	25	591.5
8. Nernst glower at 1.50 w. p. c.	31	586.7
9. Nitrogen filled tungsten:		
at 1.00 w. p. c.	34	586.0
at 0.50 w. p. c.	45	584.5
at 0.35 w. p. c.	53	584.0
10. Mercury-vapor arc	70	490.0
11. Helium tube	32	598.0
12. Neon tube	6	605.0
13. Crater of carbon arc:		
at 1.8 amperes	59	584.6
at 3.2 amperes	62	584.6
at 5.0 amperes	67	583.4
14. Acetylene flame (flat)	36	585.5

In case of the electric glow lamp sources, color analyses were made over the entire range of operation, that is, from the point at which the filament was just glowing up to the maximum current that the filament would carry. Each lamp was carefully photometered over the entire range. The photometric measurements were made on a 12-foot (3.66 m.) bench photometer of the National Physical Laboratory type. The standard lamps used were from the National Physical Laboratory. The electrical measurements were made partially by the potentiometer method and partially with laboratory volt and ammeters. From the photometric measurements the efficiency of each lamp in watts per mean horizontal candle-power (m. h. cp.) over the entire range of use was computed.

[5] Nutting, P. G.; *Bull. Bureau Standards*, vol. VIII, No. 3, p. 487.

After the photometric measurements and color analyses had been made the lamps were broken and the dimensions of the filament carefully measured. From the data thus obtained the area of the radiating surface of each filament was computed; and hence it was possible to determine the energy (in watts) radiated per unit area of radiating surface. The energy input was taken as equal to the energy radiated, loss by conduction along leading-in wires being neglected.

TABLE II.—NERNST GLOWER.

Rating: 110 volt, 0.8 amp.

Dimensions of filament: Length, 13.2 mm.; diameter, 1.03 mm.; surface area, 42.7 mm.^{2}

Glower characteristics						Color	
Amp.	Volts	Watts	M.h.cp.	$\frac{\text{Watts}}{\text{m.h.cp.}}$	$\frac{\text{Watts}}{\text{mm}^2}$	% white	Hue
0.20	79.5	15.9	0.35	45.0	0.372	13.5	592.5
0.30	87.0	26.0	2.17	12.0	0.610	15.8	591.0
0.40	94.0	37.6	7.52	5.0	0.88	18.0	590.0
0.50	95.6	47.8	14.5	3.30	1.12	22.0	588.5
0.60	98.3	59.0	24.4	2.42	1.38	24.8	587.5
0.70	101.3	70.9	38.3	1.85	1.66	28.6	587.0
0.80	102.5	82.0	57.0	1.44	1.92	32.5	586.2
0.85	102.5	87.1	68.0	1.28	2.04	33.4	586.0
0.90	102.5	92.3	78.1	1.18	2.16	35.0	586.0
0.80	102.0	81.6	56.6	1.44	1.91	29.9	586.5

TABLE IIa.—NERNST GLOWER.

Rating: 110 volt, 0.8 amp.

Dimensions of filament: Length, 13.0 mm.; diameter, 1.01 mm.; surface area, 41.3 mm.^{2}

Lamp characteristics						Color	
Amp.	Volts	Watts	M.h.cp.	$\frac{\text{Watts}}{\text{m.h.cp.}}$	$\frac{\text{Watts}}{\text{mm}^2}$	% white	Hue
0.050	170.0	8.5	—	—	0.206	6.4	598.5
0.080	112.0	9.0	—	—	0.218	9.0	597.1
0.100	90.0	9.0	—	—	0.218	10.5	595.6
0.138	76.0	10.5	0.04	240.0	0.254	9.1	594.6
0.195	72.7	12.0	0.07	140.0	0.291	10.9	593.9
0.233	77.3	18.0	0.667	27.0	0.436	13.0	592.4
0.215	76.7	16.5	0.485	34.0	0.400	13.6	593.0
0.290	81.6	23.5	1.47	16.0	0.569	16.7	591.6
0.400	87.5	35.0	7.00	5.00	0.848	20.3	590.8
0.550	94.6	52.0	18.25	2.85	1.258	22.8	589.2
0.665	96.3	64.0	31.50	2.03	1.500	25.3	588.1
0.825	97.2	81.0	59.60	1.36	1.960	30.5	587.0

In Table II and IIa are given the results of the measurements made on two similar glower lamps. In Fig. 2 this data is plotted as curves, per cent. white (curve A) and wave-length of domi-

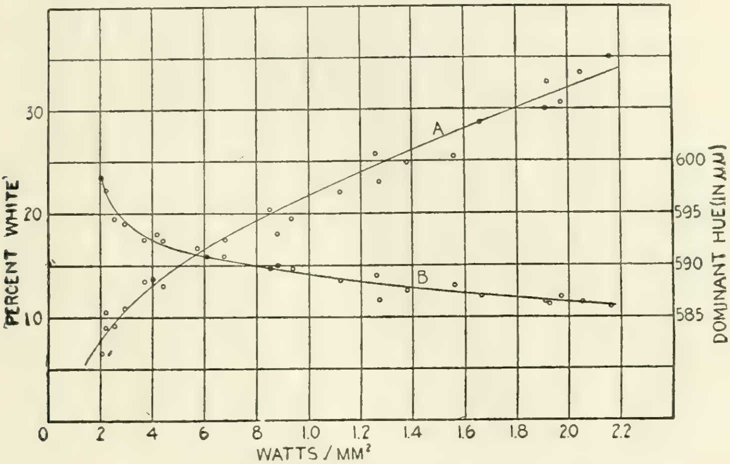

Fig. 2.—Variation in color of Nernst glower with watts radiated per mm².

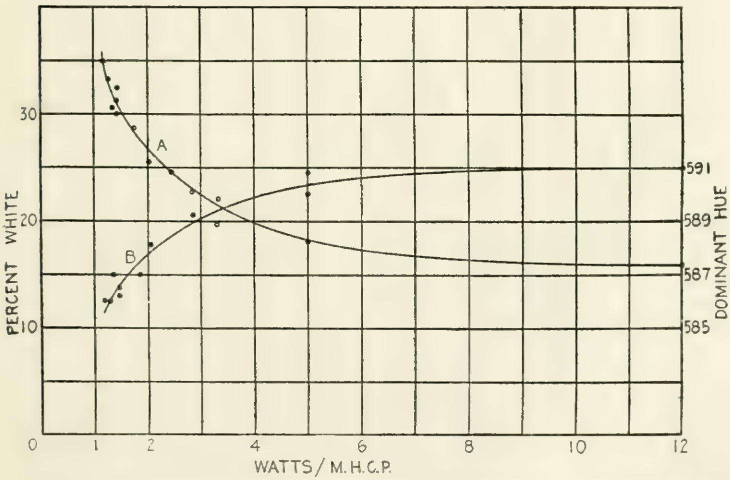

Fig. 2a.—Variation in color of Nernst glower with efficiency in watts/m.h.cp.

nant hue as ordinates against energy radiated per mm.² of radiating surface as abscissae. In all cases per cent. white curves are designated by the letter A, while the hue curves are

marked B. In Fig. 2a the same data are given in a different form, the color (per cent. white and hue) being plotted as ordinates against efficiency in watts per m. h. cp. as abscissae. There

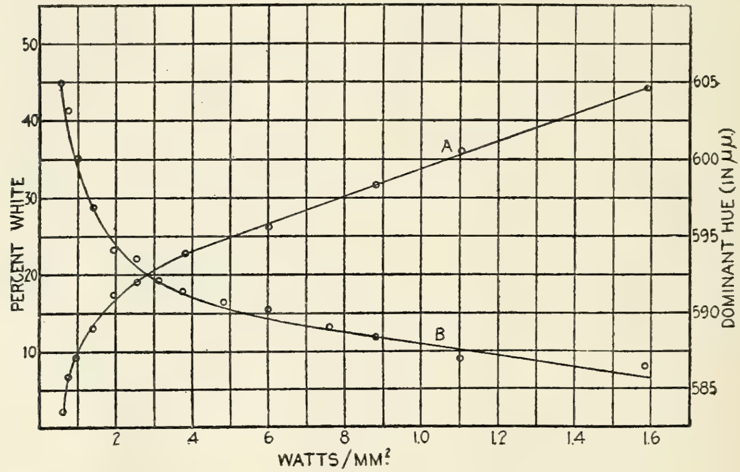

Fig. 3.—Variation in color of ordinary tungsten lamp with watts radiated for mm^2.

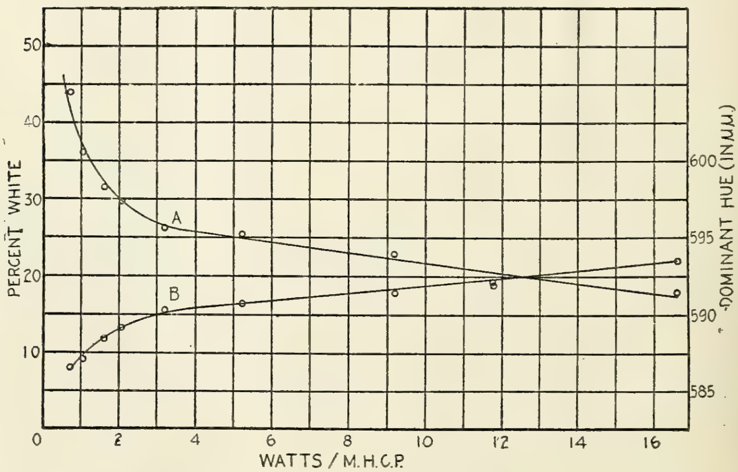

Fig. 3a.—Variation in color of ordinary tungsten with efficiency in watts/m.h.cp.

is some difference in the results obtained with the two glowers. This is probably due to the fact that in case of the one used in IIa the glower characteristics were measured while the glower

was fresh and had not been used long or above rating; while the glower used in Table II had been used for some time and run above its normal rating before the electrical and photometric measurements were made. However, in plotting the curves, all

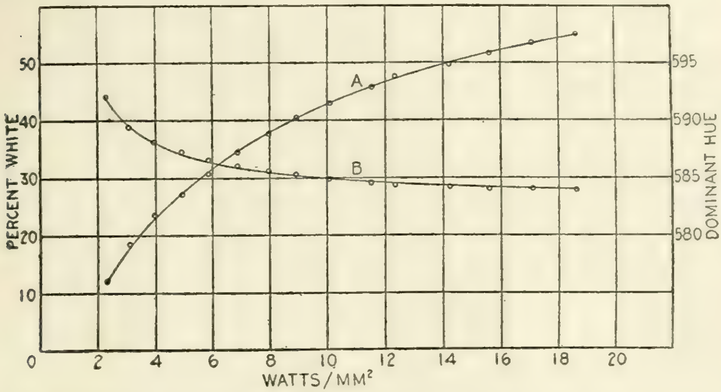

Fig. 4.—Variation in color of nitrogen-filled tungsten lamp with watts radiated per mm.

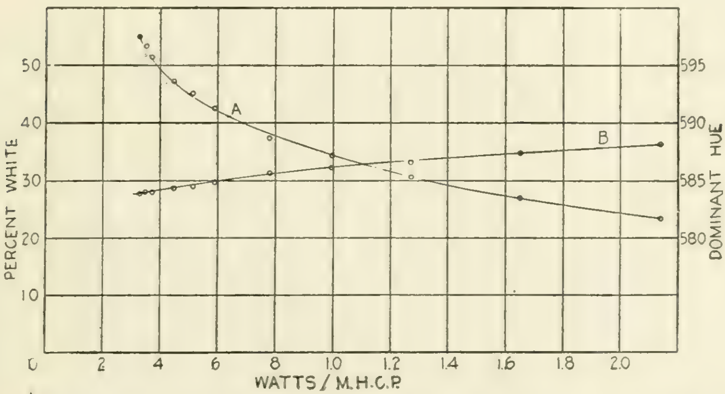

Fig. 4a.—Variation in color of nitrogen-filled tungsten lamp with efficiency in watts/m.h.cp.

the data from both glowers were used and the curves drawn in the most probable position.

In Table III are given the data obtained with an ordinary tungsten glow lamp, over a range of efficiency from 653 watts/m. h. cp. to 0.703 watts/m. h. cp. In Figs. 3 and 3a

TABLE III.—Ordinary Tungsten Glow Lamp.

Rating: 115 volt, 25 watt.
Dimensions of filament: Length, 250 mm.; diameter, 0.02 mm.; surface area, 28.3 mm.^{2}

Lamp characteristics						Color	
Amp.	Volts	Watts	M.h.cp.	Watts / m.h.cp.	Watts / mm^2	% white	Hue
0.073	21	1.53	0.01	653.0	0.0542	—	604.9
0.083	25	2.08	0.04	169.0	0.0737	6.76	603.16
0.095	29	2.76	0.07	129.0	0.0976	9.04	600.04
0.109	36	3.92	0.15	87.0	0.1380	13.03	596.96
0.123	44	5.41	0.45	38.7	0.1922	17.38	594.08
0.140	54	7.56	1.10	16.64	0.2670	18.3	593.5
0.148	59	8.74	1.60	11.8	0.3110	18.91	592.06
0.160	66	10.57	2.50	9.18	0.3730	22.94	591.4
0.176	78	13.73	4.87	5.2	0.4850	25.32	590.7
0.190	89	16.92	8.30	3.14	0.6000	26.02	590.3
0.208	103	21.92	14.62	2.02	0.759	29.55	589.06
0.220	113	24.85	20.30	1.56	0.878	31.63	588.39
0.240	130	31.10	30.00	1.036	1.101	36.00	587.0
0.278	162	45.00	64.00	0.703	1.590	44.00	586.5

TABLE IV.—Nitrogen-filled Tungsten Lamp.

Rating: 55 volt, 31.5 amp., 5,000 cp.
Dimensions of filament: Length, 520 mm.; diameter, 0.61 mm.; surface area, 1,000 mm.^{2}

Lamp characteristics						Color	
Volts	Amp.	Watts	M.h.cp.	Watts / m.h.cp.	Watts / mm^2	% white	Hue
15	15.5	232	52	4.46	0.232	12.0	592.0
18	17.2	310	92	3.37	0.310	18.5	589.4
21	18.8	395	185	2.14	0.395	23.4	588.2
24	20.3	487	295	1.65	0.487	27.0	587.4
27	21.6	584	460	1.27	0.584	30.6	586.6
30	22.9	687	690	0.996	0.687	34.2	586.1
33	24.1	795	1020	0.780	0.795	37.2	585.6
36	25.3	912	1330	0.685	0.912	40.1	585.2
39	26.4	1030	1750	0.588	1.030	42.7	584.8
42	27.5	1154	2240	0.515	1.154	45.3	584.5
45	28.6	1288	2880	0.448	1.288	47.3	584.3
48	29.6	1420	3520	0.403	1.420	49.5	584.2
51	30.6	1560	4200	0.372	1.560	51.5	584.0
54	31.6	1708	4850	0.352	1.708	53.4	584.0
57	32.7	1865	5600	0.334	1.865	55.0	583.9

these data are given as curves plotted in the first case, Fig. 3, against watts radiated per mm.[2] of filament surface as abscissae and in the second, Fig. 3a, against efficiency in watts per m. h. cp.

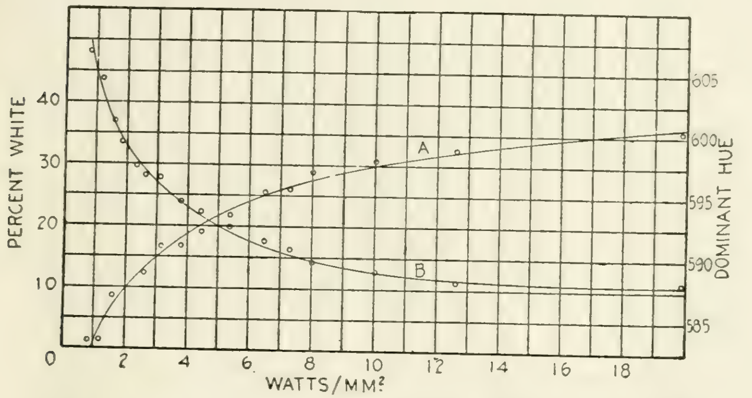

Fig. 5.—Variation in color of carbon glow lamp with watts radiated per mm².

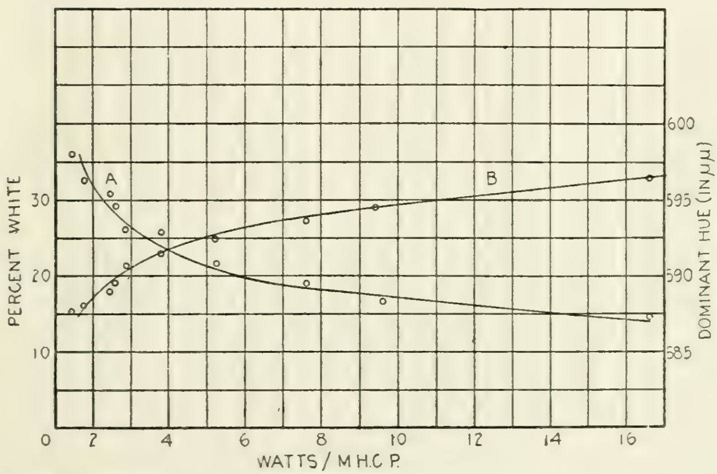

Fig. 5a.—Variation in color of carbon glow lamp with efficiency in watts/m.h.cp.

In Table IV are given the color analyses of the light given by a 5,000-cp. nitrogen-filled tungsten glow lamp operated at various efficiencies from 446 to 0.334 watts per m. h. cp. The data are

given as curves in Figs. 4 and 4a, the co-ordinates being the same as in previous cases.

In Table V are given the data on an ordinary carbon glow lamp operating from an efficiency of 225 watts/m. h. cp. up to 1.38 watts/m. h. cp. As in previous cases the data are presented as curves in Figs. 5 and 5a.

TABLE V.—CARBON GLOW LAMP.

Rating: 115 volt, 16 cp.

Dimensions of filament: Length, 23.4 cm.; diameter, 0.12 mm.; surface area, 88.4 mm.^{2}

Lamp characteristics						Color	
Amp.	Volts	Watts	M.h.cp.	Watts / m.h.cp.	Watts / mm^2	% white	Hue
0.160	42.5	6.8	—	—	0.077	0	606.7
0.200	51.0	10.2	0.04	255.0	0.115	1.3	604.4
0.238	59.0	14.1	0.18	128.0	0.159	8.7	601.0
0.259	63.5	16.5	0.34	48.1	0.186	8.0	599.2
0.289	70.0	20.2	0.65	31.1	0.229	10.9	598.3
0.312	74.5	23.2	0.95	24.5	0.263	12.3	596.6
0.340	80.5	27.4	1.65	16.6	0.310	15.0	596.4
0.380	89.0	33.8	3.60	9.39	0.383	16.6	594.5
0.414	95.0	39.4	5.18	7.62	0.446	19.1	593.7
0.452	104.2	47.1	9.00	5.22	0.533	21.9	592.4
0.500	114.5	57.2	15.00	3.82	0.648	25.5	591.5
0.531	121.0	64.2	22.5	2.86	0.727	25.9	590.7
0.560	127.0	71.1	28.0	2.54	0.805	28.9	589.6
0.635	143.0	90.9	37.0	2.46	1.03	30.8	588.9
0.707	158.0	111.6	62.5	1.78	1.26	32.4	588.1
0.860	204.0	175.5	155.0	1.13	1.99	35.7	588.1

In Fig. 6 the per cent. white curves of the four sources are given plotted against the watts/mm.^{2} radiation, and in Fig. 7 the hue curves are shown also plotted against watts/mm.^{2} as abscissae. The numbers near the small circles in Figs. 6 and 7 indicate the efficiencies in watts/m. h. cp. at those points on the curves.

The color of the light emitted by any lamp does not depend upon the shape of the filament or the distribution curves of the lamp, but for filaments of a given material is a function of the temperature, hence of the absolute efficiency of the lamp.

In this respect the color analysis of a source is a unique characteristic for other means of specifying the efficiency of a lamp

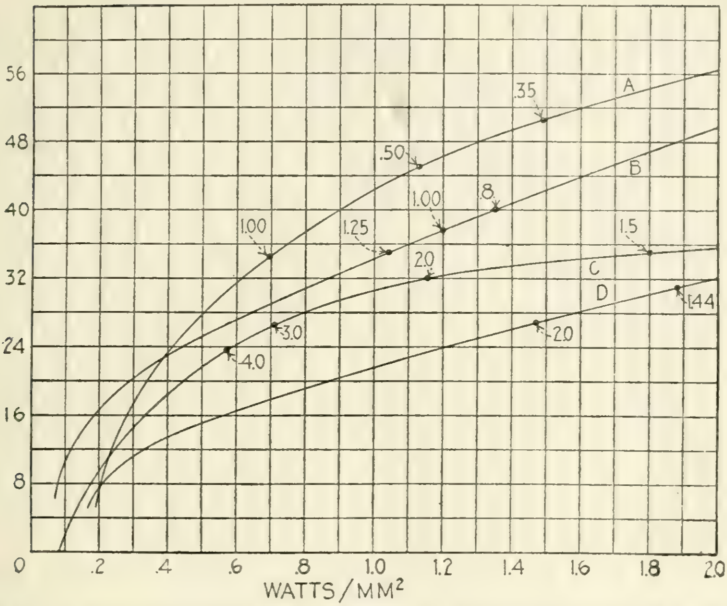

Fig. 6.—Per cent. white curves for four sources. A, nitrogen-filled tungsten lamp; B ordinary tungsten lamp; C, carbon glow lamp; D, Nernst glower lamp.

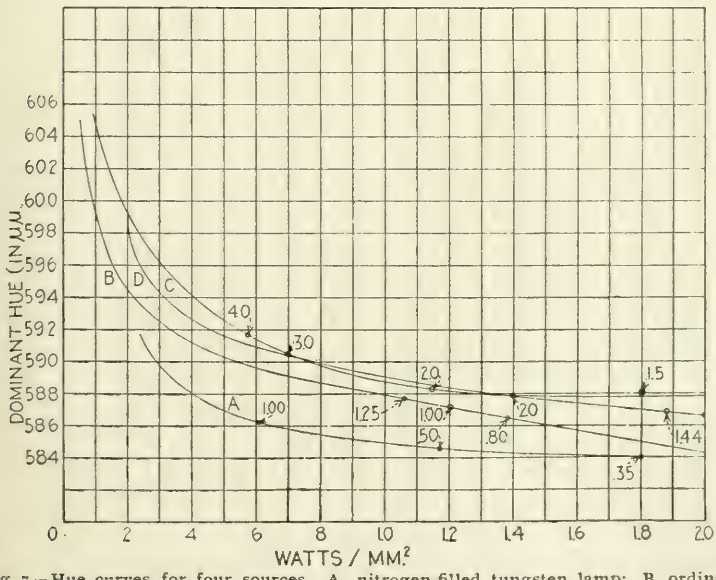

Fig. 7.—Hue curves for four sources. A, nitrogen-filled tungsten lamp; B, ordinary tungsten; C, carbon glow lamp; D, Nernst glower lamp.

such as watts/m. h. cp., watts/m. h. s. cp. etc., depend upon the geometrical form in which the filament is mounted.

In case it is desired to set a number of lamps to operate at a given efficiency the colorimeter method could be used to great advantage. The procedure in such a case would be to set the scales of the instrument to correspond to the analysis of the desired efficiency, then place the lamp to be set at S_2, Fig. 1, and by varying the voltage produce a color match in the field of the instrument. This could be done quite rapidly and the precision obtainable would be as good or better than by using the color screen method. The precision obtainable in a single reading is of the order of ± 3 per cent. in the per cent. white reading and $\pm$ 0.5 $\mu\mu$ in the wave-length of dominant hue and by taking a number of observations the probable error can be greatly reduced. This method offers a means of specifying the efficiency of a lamp in absolute terms, free from any arbitrary factors such as color screens and filters.

DISCUSSION.

MR. W. R. MOTT: This paper is of special interest and of great value. However, I would like to ask Mr. Jones how he could convert his data to the usual system of so many parts of red, green and blue light. Dr. Block, a German illuminating engineer, has given a summary of much work on colors of illuminants, in an article which is printed in *Elektrotechnische Zeitschrift,* November 13, 1913, page 1306. Dr. Block uses the ratios of red/green and blue/green. His results are represented in the Maxwell triangular form by Mr. Jasse.[6] The values for sunlight are quite different from those of clouded skies. He uses the clouded sky as a standard instead of sunlight. The daylight, clouded sky, gave red, 0.333; green, 0.333; blue, 0.333. Daylight, blue sky, gave red, 0.272; green, 0.337; blue, 0.391. Sunlight gave red 0.377; green, 0.325; blue, 0.298.

In color matching, sunlight is not as desirable as north sky light and therefore sunlight is merely a secondary standard and perhaps as good as any yet offered, in spite of the fact that the sunlight at Pittsburgh, Niagara Falls and Pikes Peak changes from a yellowish white to a bluish white.

The selection of sunlight as a color standard for white light

[6] *Elektrotechnische Zeitschrift,* December 18, 1913, p. 1454.

makes the ordinary incandescent lamps appear better than they really are.

In the flame lighting white light of any desired composition can be made, because the spectral lines are numerous and close together. But there is considerable disagreement as to what different people think they want. This leads to some confusion. The yellow flame carbon is rich in red, yellow and green light, but low in blue, as in the case of ordinary carbon incandescent lamps. Not much blue light is required by the yellow flame carbon to give a light of whiter color than that of the tungsten lamp. There is a white called pearl white. It is the chief flame illuminant in American and European cities, and is excellent because of its pleasing color and high illuminating power. There is also a snow white. The difference between a pearl white and a snow white is about as great as that between yellow and pearl white. The snow white flame arc is used in photographic engraving and in color matching. Its color value is about the same as that given by north skylights.

In passing, it may be interesting to mention that in the illumination of jewelry stores the snow white light is very effective in bringing out the desirable blue sparkle of diamonds, cut glass, etc. Also, in fish markets the blue scales of fish, to appear fresh, must be illuminated by white light.

In most of the published articles on flame carbons the authors have failed to designate the kind of white light in referring to white carbons. The usual city illumination is what is called pearl white.

I submit for consideration the following table which has been compiled from Dr. Block's paper referred to above:

	Red	Green	Blue
1. Sunlight	0.377	0.325	0.298
2. Stearin candle	0.776	0.167	0.057
3. Tungsten at 1.2 watts per Hefner candle	0.643	0.237	0.120
4. High candle-power tungsten gas-filled lamp, 0.5 watt per Hefner candle	0.554	0.276	0.170
5. Mercury-vapor lamp	0.064	0.706	0.230
6. Neon tube	0.955	0.0425	0.0025
7. Acetylene	0.639	0.243	0.118
8. Flame arc, pearl white	0.423	0.369	0.208
9. Flame arc, yellow	0.434	0.439	0.127
10. Flame arc, red	0.770	0.141	0.089

The value for tungsten lamps in the blue is a shade less than that of the yellow flame arc.

Dr. H. E. Ives: This paper is of very great interest to me, as I need scarcely say, since previous work of mine is quoted several times. I may perhaps be pardoned if I speak perhaps rather at length on the question of the method of color measurement here used. The author has several times made an implied comparison between the three-color method and the monochromatic method, in which he uses the rather favored term "arbitrary." To the best of my knowledge this method was originated by Sir William Abeny back in the 80's, and a number of measurements were published by him. Five or six years ago while I was in the Bureau of Standards in Washington, I published a paper entitled "The Daylight Efficiency of Illuminants," and used this method in calculating the results from known data. I suggested at that time that the method might be worked out practically if some means were provided for measuring the relative brightness of the pure spectral hue and the white light. I was very much interested in this method because it appeared to possess certain advantages over the three-color or tri-chromatic method. In the three-color method, the measurement is always made by using colors which are far separated in the spectrum; one measures a yellow by mixing a monochromatic red at one end of the spectrum and a green in the middle. There is every opportunity for differences in color vision in different observers. By using this monochromatic method a yellow of any saturation would be matched by a mixture in which the dominant part was spectrum yellow. Consequently a greater uniformity between matches by different individuals might be expected.

Several things, however, must first be definitely decided before the monochromatic method becomes one of precision; first, there must be a standard of white light; second, we must have some means of reproducing that white light at any time or place; third, and most important of all, we must have some definite, well worked out and authorized method of measuring the brightness of the spectrum color against the white. Now, as for a standard white, there is a paper in the Transactions of the

Society[7] in which I have brought together a great many measurements on daylight. I propose there noon sunlight as the most representative white light. I also pointed out that there is a great convenience in having some formulas by which to express our experimental values, and that the black body at 5,000 deg. seemed to offer this formula. I would like to have it emphasized, however, that the proposition here stated, that it is "more logical" to define standard white light as the light from the noon sun, is not altogether original with the writer. My own sentiment would be that if the 5,000 deg. black body is now shown not to be the nearest formula to sunlight then change the formula; but I entirely agree with the author that noon sunlight is a good choice for "white" light.

As to some means of permanently reproducing this white sunlight, we all know that sunlight is extremely variable and in a great many places we don't have enough of it to work with. There has recently been described an instrument[8] by which any spectrum energy distribution, such as white light, can be produced at will. So we have two of the three things that seem to be necessary.

Finally, this question of measuring the relative brightness of the spectrum hue and color, as probably many of you know, I have been working for four or five years on exactly that problem, and I think we may say that we are getting close to some kind of solution. Now, as I say, the author speaks of the three-color method as being arbitrary in the sense that we use selected colors. Now my proposition is that the method he uses here substitutes for something arbitrary something which is indeterminate, in that in the three-color method we have two fields absolutely alike in brightness and color—the very best conditions for photometric precision; by this other method, one is forced to make a measurement of a white against a pure spectrum color. I think it takes courage to make measurements which involve such a comparison in the present state of these measurements. So that, to sum up that part of my discussion, it seems to me that in Table I the author gives us very valuable data as to the

[7] H. E. Ives, Color Measurements of Illuminants—A Resume; TRANS. I. E. S., Vol. V, p. 189.

[8] This instrument is described in a paper, The Development of Daylight Glass, by E. J. Brady, to appear in No. 9, Vol. IX, TRANS. I. E. S.

hue which must be mixed with the white to match these illuminants, but the percentages of white values are, as I say, indeterminate. As to the three-color method being arbitrary, the gentleman who spoke before me asked how these monochromatic measurements could be reduced to the three-color basis. There is a paper in the TRANSACTIONS of the Illuminating Engineering Society of 1910 in which the method of reduction of three-color measurements and any other kind to a basis of three sensations, that is to a common basis, is pretty fully outlined; so that a method does exist. I think that this whole question of the measurement of color must wait until we have those methods and that data on the measurement of brightness, color and so on, which will enable us to reduce all these measurements from one system to another or to a common system.

In reference to the work of Voege and Jasse I merely wish to say that the apparent disagreement between their results and mine is not at all to be ascribed to differences between their white light and ours, but to the fact that they have utterly misunderstood the use of the geometric construction known as the color triangle. The color triangle shows how, by mixing certain colors, others will be obtained. For instance, by mixing red and green light, yellow will be obtained. Now they have merely plotted spectrophotometric values taken at three wave-lengths or triangular co-ordinates. They have overlooked the fact that their own plots are entirely arbitrary because of their arbitrary choice of wave-lengths, and do not seem to be aware even of the fact that, in the true mixture triangle, colors plot at different positions depending on the three mixture primaries used. The work of Voege and Jasse simply does not enter into the discussion at the present time.

There does exist a complete theoretical method backed up by enough data to show the entire practicability of reducing all color measurements to a unified system. But such measurements must wait for the solution of a number of these problems I have mentioned.

MR. W. C. MOORE: I would like to point out that, if we exclude those sources which give pure line spectra and take only those sources that give continuous spectra, the data in Mr. Jones'

paper show that the crater of the carbon arc, especially at the higher amperages, gives a greater per cent. of white light than any other illuminant which he studied. This means that the light from a pure carbon crater is better than any other artificial light for color matching. It is interesting to note that the hue used to dilute white light in matching the crater of the carbon arc is about the same as that for matching the gas-filled tungsten at 45 watts per candle, but that the percentage of white light is greater for the crater of the carbon arc, when operated at 5 amperes by about 22 per cent.

MR. M. LUCKIESH: I would say a word regarding the two methods of colorimetry mentioned in this paper. They are based on well-known and apparently sound principles, but often both are weak because they give results that are quite misleading, owing to the fact that the methods are not sufficiently analytical. I am inclined to favor the method of colorimetry which measures the three factors—hue, saturation and luminosity. However, colorimetric data as applied to illuminating engineering are often very misleading. For instance by the three-color method I find that the color of the light from a quartz mercury arc is about the same as "average daylight," yet we all know there is a tremendous difference between the two lights as is readily apparent on viewing colored objects under these lights.

In regard to Table I, the "per cent. white" light is what we would call the "white light efficiency" of the illuminant provided the white light standard is correct. In the case of illuminants having continuous spectra such as the light from a tungsten lamp, this "per cent. white" should be the true "average daylight" efficiency. However I note from No. 6 of Table I that the amount of white light in the light from a tungsten lamp operating at 1.25 w. p. c. is given as 35 per cent. Computations by Mr. Cady and myself from spectrophotometric data using the white light that Dr. Ives has established by collecting data from a number of experimenters and his own work, gives a "white light efficiency" of 14 per cent. for the tungsten lamp operating at 1.25 w. p. m. h. c. instead of 35 per cent. For the nitrogen-filled tungsten lamp operating at 0.5 w. p. m. h. c., Mr. Jones obtains a "white light efficiency" of 45 per cent. while we ob-

tained 25 per cent. This is a large difference, but it seems to me that we can safely rely on computations from spectrophotometric data using as our white light the mean of the results obtained for daylight by a number of individuals. It is possible the difference noted is due entirely to the use of different white light standards. Of course the computed values depend upon the extreme short wave-length considered. It would appear that our computed daylight is too accurate for practical purposes.

Another apparent inconsistency is found on comparing the "per cent. white" obtained by Mr. Jones in the lights from the vacuum tungsten lamp operating at 1.25 w. p. c. and the nitrogen-filled tungsten lamp operating at 1.00 w. p. c. The values are practically the same, yet the light from a gas-filled lamp is whiter than that from a vacuum lamp when burning at the *same* luminous efficiency. By assuming probable reduction factors the same inconsistency is found in Fig. 3a. This also illustrates that it is quite unsatisfactory to designate the luminous efficiency of a light source in watts per mean horizontal candle. It seems that this society has advanced sufficiently to strongly recommend that luminous efficiencies of incandescent lamps be expressed in lumens per watt.

Dr. H. E. Ives: I wish to add one word of explanation. Mr. Luckiesh has called attention to No. 6, the tungsten lamp, of Table No. I, as having a "per cent. white" of 35, and he believes this is in contradiction to the calculated daylight efficiencies. If I may refer once more to an ancient paper of mine in the Bulletin of the Bureau of Standards, it was there pointed out that there can be defined two different "white light efficiencies," one the "white light efficiency" in which there is an arbitrary factor, namely, at what point in the spectrum one starts the screening, and the other, the white sensation efficiency which shows the very greatest amount of subjective white one could get by any process. In the case of the tungsten lamp, if one puts an absorption band through the yellow, one could make a white light at much less sacrifice than by screening the whole spectrum. The white sensation efficiency corresponds to the "per cent. white" of Mr. Jones'. It is always higher than the "white light efficiency," consequently this 35 is not necessarily too high.

Mr. M. Luckiesh: I appreciate Dr. Ives point. I had that in mind when I made my remarks and accordingly I chose sources that had continuous spectra. What Dr. Ives states does not explain the discrepancy in the cases which I have chosen. It could apply in a case of line spectra or banded spectra.

Dr. C. H. Sharp: The possible practical application of the colorimeter to rating lamps depends upon how close the watts per candle can be duplicated and therefore the life of the lamp predicted. I wish to call specific attention to the use of the term "watts per candle" as efficiency. I thought we had got way beyond that in the Illuminating Engineering Society, but it crops out here again and simply shows how long it takes those old heresies to die off.

Dr. H. P. Gage: The Corning Glass Works is experimenting with this instrument for settling some of the problems in signal glass, and I think the results will show that it is a good method. Whether it is a practical method to use with incandescent lamps, as suggested by Dr. Sharp, cannot be determined without considerable experiment. As Dr. Ives has pointed out, a good, reproducible daylight is really necessary in the use of this instrument, but there is no doubt that this colorimeter throws a great deal of light on the problem of white and colored illuminants.

Mr. L. A. Jones (Communicated in reply): A large part of the discussion seems to deal with the relative merits of the trichromatic and monochromatic methods of color analysis. This paper was in no sense intended as a defense of the monochromatic method. Questions regarding the instrument and method are referred for answer to the article by Dr. Nutting in the Bulletin of the Bureau of Standards, Paper No. 187. In that paper due credit is given to Sir William Abney, who first made use of this method of color analysis.

Now in regard to the standard white: It seems to be the opinion of some that sunlight is quite variable in color. This is not in accord with the results of measurements made by the author. The facts on which this conclusion is based are as follows:

The spectral energy distribution in the light from an acetylene flame appears to be remarkably constant. This is indicated by

measurements made by Nicols, G. W. Stewart, Coblentz, and by Dr. Nutting and myself. The distribution is independent of the way in which the gas is generated and the type of burner that is used. These facts indicate that the color of the flame is also very constant. Color analyses of the acetylene flame have been made over a long period of time, some in Washington, D. C., and some in Rochester, N. Y., using noon sun as a standard white. No appreciable variation in the analyses has been found. This indicates either that both noon sun and the acetylene flame are very constant in color or that the two always happen to change at the same time and in the same direction. The latter condition is very improbable.

In the following table are given determinations on the color of acetylene made at different times. Each value is an individual setting not the average of a set:

		Per cent. white	Hue
Washington, D. C.,	June, 1912	38.4	585.8
	July, 1912	39.2	586.0
	July, 1912	37.9	585.0
	Aug., 1912	37.6	586.0
	Sept., 1912	35.8	587.0
	Oct., 1912	37.5	586.4
Rochester, N. Y.,	June, 1914	35.3	586.5
	July, 1914	36.0	584.8
	July, 1914	39.0	586.0
	Sept., 1914	35.7	585.8
	Sept., 1914	38.7	585.5
		37.4	585.9

These are only a few typical readings selected entirely at random from a large number. The value given in the paper Table I is the average of all the readings taken and is more nearly correct than the average of the few given here.

Very extensive and precise data by Abbot and Fowle (*Am. Astroph.* Abs. II, 105-113) on solar emission and atmospheric absorption extending over a period of seven years and taken at stations differing greatly in altitude indicate that very little variation in color is to be expected from day to day and at different altitudes. Unfortunately, I have not been able to make color measurements on sunlight at many places widely separated.

However, I doubt very much if it would be possible to detect any appreciable difference in the color of noon sunlight (sky light excluded) at places differing greatly in latitude and altitude. I wish to emphasize again my belief that noon sunlight should be adopted as the primary standard of white light.

The discrepancies between my values of per cent. white and the values for white light efficiency computed by Mr. Luckiesh may easily be accounted for by the fact that he has used a daylight standard white while my standard white is noon sun. He does not state the details of his method for computing the per cent. white from the spectrophotometric curve, but unless it is quite an improvement over the ordinary method, I certainly can not agree with the gentleman's statement that we can safely rely on computations from spectrophotometric data.

The nitrogen-filled tungsten lamp used in this work was a 5,000-cp. unit of a type made especially for the laboratory with which I am connected. Facilities for determining the reduction factor of these lamps were not at the time available in our laboratory. Hence, I cannot give any data in regard to the relative luminous efficiencies of the various lamps investigated.

In regard to the precision obtainable in setting a lamp to a given efficiency by this method: As was stated in the paper the precision obtainable in a single setting is about ± 3 per cent. in the per cent. white value. Now the corresponding precision in the efficiency will depend upon the slope of the per cent. white curve at the point at which it is desired to set the efficiency. For example, take an ordinary tungsten lamp at 1.25 w. p. c. In this case ± 3 per cent. in the per cent. white value is equivalent to ± 0.08 in w. p. c.

THE DEVELOPMENT OF THE FLAME CARBON.*

BY R. B. CHILLAS, JR.

Synopsis: The development of the arc lamp and carbons is traced briefly from the open arc, the enclosed arc, and the open flame arc, to the present high efficiency enclosed flame arc. Some of the difficulties met with since 1911 in the course of the work are presented, together with the means taken to overcome them. The considerations leading to the choice of the size of carbons, and of the feeding mechanism of the lamps, are discussed; other minor points of interest are mentioned. The direction along which improvements in the carbon are being made is pointed out, together with the importance of proper care in certain details.

In the summer of 1876, Mr. Charles F. Brush exhibited the first practical plain carbon open arc lamp in the Public Square of Cleveland. Great crowds of people were assembled, many of whom brought smoked glasses to protect their eyes. It may be interesting to note that there are a good many thousand open arc lamps in use in this country and abroad to-day. The next important step was made in 1894 when Mr. L. B. Marks, the first president of this Society, brought out a practical enclosed arc lamp. This must be considered as a marked improvement over the open arc lamp, due to its lower maintenance cost, though it is of somewhat lower efficiency. With the improvement in the lamp, came a corresponding improvement in the electrodes.

From this point, the progress has been along a somewhat different line. It has been known for some time that certain chemicals or metallic salts, when introduced in the carbon arc, greatly changed its characteristics, by tending to lengthen the arc, improve its steadiness and in some cases to increase the light. The realization of the inherent possibilities of this fact led to the beginning of work on the development of the flame carbon. Prominent among the names connected with this development was that of Bremer, who brought out a flame arc lamp in 1898.

The first flame carbons were solid or homogeneous impregnated ones. The early experimenters used these carbons in verti-

* A paper read at a meeting of the Pittsburgh section of the Illuminating Engineering Society held in Pittsburgh, Pa., April 17, 1914.

cal trim open arc lamps. Great difficulties arose in maintaining the lamps in operation, due to slag or an insulating deposit on the points of the carbons.

Consider for a moment just what a flame carbon is. When an arc is formed between two pure carbon points the tips of the carbons become heated and give off a vapor of carbon which is conducting at the high temperature maintained by the passage of the current through it. The heat developed continues to supply vapor to the arc and also to produce light mainly by incandescence of the carbon tips.

Suppose now that instead of the pure carbon, one uses an electrode composed of carbon together with a calcium compound, for example, intimately incorporated throughout the body of the electrode. When the arc is formed, what happens? The heat of the arc forms carbon vapor, which is always present in the arc, and in addition volatilizes some of the chemicals that lie immediately adjacent to the craters. This vapor is carried into the arc and there becomes luminescent, or as is said, it is a flame arc.

Next, what becomes of these arc vapors? The carbon vapor burns producing carbon monoxid or carbon dioxid, the disposal of these gases requiring no special consideration at this point. The vapor of the chemicals, however, when it cools, forms very finely divided solid particles or dust. At this point the principal problems of the lamp manufacturer and the carbon maker enter. The carbon maker must produce an electrode which will give light as efficiently as possible and at the same time so select the chemicals to be used that all will be driven off from the arc as fast as the carbon is consumed. The lamp manufacturer must construct a lamp which will utilize the light to the best obtainable degree and at the same time take care of the rather voluminous amount of dust produced. These two problems should be kept clearly in view, as they are of assistance in following the development of both lamp and carbon. It must be remembered of course that the two overlap to a large extent.

Return now to the first experiments with flame carbons and follow the development to the present time. Bremer used a vertical trim, open arc lamp burning solid or impregnated flame carbons. Several causes operated against this lamp, the prin-

cipal one being that such carbons have a tendency to burn to the characteristic tapering point of open arc carbons. In so doing the mineral matter is left behind at the point. Moreover as it accumulates and is fused by the arc it sooner or later renders the lamp inoperative, or, as is said, it slags out. A great deal of work was done to perfect this type of lamp but without avail.

The next step was to surround the flame carbon with a thin shell of pure or unimpregnated carbon, so that when oxidation takes place the shell in burning away does not leave behind any mineral matter to form a slag. This feature solved the difficulty and increased the reliability of the carbons to some extent.

However, other difficulties then became apparent. It was found that the flame material was not completely volatilized by the arc, but that after some time there would be formed an insulating bead or coating of some of the flame material over the tips of the carbons. With this general type of carbon both hard and soft flame cores have been tried, with a great many different combinations of the light-giving materials. (Some lamps in use to-day burn this type of electrode.)

The next step in the development came when the present inclined or converging trim was adopted. In this lamp, the arc is formed between the lower ends of two converging carbons. A magnetic blow coil is so placed that a field in the region of the arc blows it downward in a fan shape. Both carbons used in this lamp are cored and are of rather small diameter. This type of lamp possesses a unique advantage in the high percentage of the total line voltage which is available at the arc.

All the flame lamps that have so far been mentioned were burned under open arc conditions and hence gave comparatively short trim life. A vigorous search was meanwhile being made by the lamp manufacturers for a means whereby longer life could be obtained.

The enclosed plain carbon arc pointed out the line to be followed. The difficulty lay in preventing a heavy deposit of dust on the enclosing glassware. After much experimenting, this has been overcome by the use of a chamber with comparatively cool condensing surfaces opening into a rather highly heated glass globe surrounding the arc. With this arrangement, properly designed,

the circulation of the air or other gases within the enclosure carries the dust away from the arc and deposits it upon the cooler parts of the condensing chamber. This then makes it possible to take care of a comparatively large quantity of dust before the amount on the globe seriously diminishes the light.

The next problem was to design a lamp and carbons which would give long trim life together with a high light-giving efficiency.

A number of very interesting steps have been made in the course of the present development which started in the middle of 1910. The first step was in the use of the already well developed inclined trim lamp to which a condensing chamber was fitted. The flame carbons used were ½ in. x 22 in. (13 x 560 mm.) of both solid impregnated and cored types. The solid carbons gave the best results, but on account of difficulties in the control of the magnetic field at the arc this line of work was set aside.

Early in 1911, some of these carbons were burned in a vertical trim enclosed lamp and showed great promise. From this time the course of the development has been mainly with this type of lamp in the line of refinements in the methods of manufacture and improvements in the character of the flame materials used. At the same time improvements have been made by the lamp makers in the way in which the dust is handled, referring particularly to the changes in the design of the economizer that have been made.

In the course of the development of lamps and carbons the question has been asked several times why the present ⅞-in. (22 mm.) carbon was adopted.

During the course of the work with the converging type of lamp mentioned above, some ⅝-in. and ⅞-in. (16 mm. and 22 mm.) diameter electrodes were made at the same time as the ½-in. x 22-in. (13 x 560 mm.) carbons. Certain manufacturing considerations entered which were against the latter size. The ⅞-in. (22 mm.) carbon greatly decreased the difficulties then existing.

To obtain the desired long-life carbon a more or less definite quantity of carbon is required. This may be obtained either in a long thin carbon, which has a rather high resistance, presents

difficult manufacturing problems and demands a long lamp; or in a shorter and thicker carbon, which has a lower resistance, is simpler to make and requires a much shorter lamp. In view of these points, the ⅞-in. (22 mm.) size was adopted, though it was to a great extent due to the fact that the first flame carbons larger than ½-in. (13 mm.) were of ⅞-in. (22 mm.) in diameter. The length adopted was 14 in. (355 mm.) as it was found that this amount of carbon was needed to give the desired 100 hours life.

With this size carbon used for both upper and lower electrodes, lamps were designed to feed the carbons at their natural burning rate, different classes of service requiring different feeding ratios.

Another phase in the development was the design of lamps of uniform feeding ratio for all types of service and the selection of carbons of such diameter as would maintain this ratio. In a comparatively short time, the number of carbon sizes required increased in number to such an extent that it soon became impracticable from the standpoint of supplying the customer always with the right carbons for his particular lamp. This condition accordingly gave way to the adoption of the original ⅞-in. (22 mm.) carbon.

Some of the minor steps that have been taken may be of interest. In order to improve the reliability of operation, a very thin pure carbon shell surrounding the flame carbon was used. In another case, a pure carbon pin of slow burning composition was placed in the center of the flame carbon. In both of these the idea involved was to have a pure carbon projection above the surface of the flame carbon, in order to improve the reliability. These features were given up, as they did not add materially to the reliability, and seriously decreased the steadiness of the light.

The present status of the development may be summed up as follows: Both lamp makers and carbon makers are aware of the great possibilities of the flame arc and are actively working on improvements. In the carbon, new and improved uses of the available light-giving materials are being made with the object of raising the efficiency. At the same time, manufacturing proc-

esses are being developed. With each increase in efficiency a corresponding increase in reliability of operation and steadiness of light is being obtained.

This makes it possible to give more attention to such factors as the economizer deposit and globe etching, by properly selecting those combinations of materials which will minimize the troubles from these causes as much as possible.

On the part of the lamp user, particular attention should be paid to the importance of cleaning the carbon holders to insure good contact. The carbon maker has adopted the copper coated holder end, to prevent trouble at this point as much as possible. However, in those cases where arcing in the holders does occur, it must be taken care of in order to avoid a cumulative effect due to the flame material contained in the carbon. Other points on the care of the lamp, such as clean economizers and clean condensing chambers, have been emphasized in several previous instances, so that it is unnecessary to go into further detail.

A NEW STANDARD LIGHT SOURCE.*

BY L. A. JONES.

Synopsis: The light source discussed and described in this paper is a cylindrical acetylene flame with a metal chimney having a re-entrant window. It provides a convenient laboratory source giving a definite quantity of light of fixed quality.

Standard light sources available for practical use in laboratory or testing work are very limited in number, those most commonly used being the Harcourt pentane lamp, the Hefner standard, and electric incandescent lamps, carbon and tungsten, that have been seasoned and standardized.

It is desirable in most work that the color of the light given by the standard be as near white as possible, and it is also very desirable, in fact necessary, in some work that the spectral energy distribution of the source be known and constant. In addition to these qualities, the source should be simple to set up and operate, and should require as little attention as possible.

The standard Hefner and the pentane lamp both require continual attention to keep them in adjustment and are very sensitive to air currents. Their intensity is affected to an appreciable extent by the humidity of the atmosphere in which they operate, and by the purity of fuel employed. The color of the light given by them is decidedly yellow, and so requires a dense blue filter to reduce it to daylight quality. These disadvantages are sufficient to exclude these standard sources from the list of available sources for practical use in laboratory and testing work.

The incandescent electric standard, when properly operated, gives results of high precision, but the apparatus required to control and to make the necessary current and voltage measurements is very expensive to install, and complicated to operate. Since the light intensity varies from four to eight times as fast as the current, the measurement of current must be made very precisely, usually requiring a potentiometer method in order to

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attain the necessary precision. The color of the tungsten standards is quite satisfactory, as it requires a filter of only medium density to reduce the light to daylight quality. But the difficulty of operating the standard at constant intensity, the expense of the apparatus necessary, and the complicated nature of the measuring apparatus make the electric standard very cumbersome for general use in a laboratory or testing room.

The acetylene flame has been used to some extent as a standard[1] and in many ways is remarkably well adapted to such a use. The color is very white and requires a filter of only medium density to reduce it to daylight. The unscreened flame is almost an exact match in color with a tungsten lamp operating at about 1.25 watts per mean horizontal candle-power. The spectral energy distribution[2] has been determined very accurately by Stewart and also by Coblentz. It is a simple matter to prepare acetylene gas of the required purity and to control and measure the gas pressure with the necessary precision.

The ordinary type of acetylene burner produces a broad flat flame which varies appreciably in color and intensity from the center to the edges. Such a flame if screened in such a way that only a small area of the most intense portion of the flame is used as the light source makes a fairly satisfactory standard, but since the screening diaphragm cannot be placed very close to the flame, errors due to parallax[3] are likely to arise. Such a flame is also very sensitive to air currents and to the ventilation conditions of the box or enclosure in which it may be placed to shield it from air currents.

A more satisfactory type of burner has been designed by Mees and Sheppard, and some data on the constancy of intensity has been published by them.[4] This burner gives a long thin cylindrical flame which is not sensitive to air currents and has a very uniform intensity over several millimeters of its length.

The object of this investigation was to determine the reliability of such a burner as a light standard. A large number of photometric measurements were made on several burners of this

[1] Fèry, C.; Journ. de Physique, IV, 632, 1908.
[2] Nutting, P. G.; Outlines of Applied Optics, p. 154.
[3] Photographic Journal, April, 1910, p. 166.
[4] Photographic Journal, July, 1910, p. 287.

type over a wide range of operating conditions. The intensity at various points along the flame and the variation of intensity with change of gas pressure was measured. From the results of these measurements the conditions tending to give the minimum variation of intensity were established. Such burners are not reproducible to the precision required for a primary standard, but must be standardized under fixed conditions by comparison on a photometer with some primary or secondary standard source of which the intensity is accurately known.

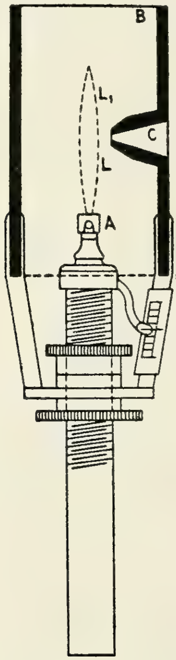

Fig. 1.—Vertical section through standard burner.

In Fig. 1 is shown a cross section of the burner as used in the investigation. The burner tip, A, is of the Bray air mixing type taking ¼ cu. ft. of gas per hour and giving a cylindrical flame about 3 mm. in diameter and 50 mm. high. The tip is mounted inside a cylindrical metal hood, B, with a rectangular opening, C, in one side. From the edges of this opening metal leaves, L, L′, extend inward to within about 2 mm. of the flame. The inner

edges of these leaves form an aperture through which a short section of the flame is viewed, and as this opening is quite close to the flame, the possibility of parallax errors is reduced to a minimum. The aperture thus formed is approximately 3 cc. high and 10 mm. wide. Thus a section of the cylindrical flame about 3 mm. long is all that is actually used as the standard light source. The acetylene used was produced in a Thorne and Hoddle generator from which it passed through a purifier containing bleaching powder and potassium chromate, and thence through a pressure regulator which maintained the line pressure constant to within 2 per cent. The pressure measurements were made with a water manometer.

The standard lamps used in making the photometric measurements were 50-volt tungsten glow lamps operating at about 1.25 watts per mean hemispherical candle-power. They were standardized at the National Physical Laboratory and the values in terms of the international candle were certified to 1 per cent. These standards were operated on a 60-volt storage battery, the electrical measurements being made with a Wolff potentiometer and a Leeds & Northrup high sensibility galvanometer. The comparison method was used in making the photometric measurements, the comparison lamp also being supplied from storage battery and measured by the potentiometer method. The photometric measurements were made on a 12 ft. (3.65 m.) bench photometer of the N. P. L. type, using a Lummer-Brodhun contrast photometer head. The readings were taken with both standard lamp and acetylene burner unscreened, and although there was a slight color difference, it was not great enough to cause any appreciable error in the settings.

A set of six burners was used, the intensity of the light given being measured with the window at different distances above the top of burner tip and at various gas pressures.

In the curves, tables and text the following symbols are used:

I = Intensity of light in candle-power.

P = Pressure of gas in cm. of water.

D = Distance (in mm.) between top of the burner tip and the middle of the window in the hood.

dI = Maximum deviation of any single determination from the mean.

TABLE I.

Burner No. 3.

P = 8 cm.

D =	16.9	18.5	20.1	21.8	23.4	25.0
Run No. 6	0.97	1.06	1.09	1.04	0.95	0.74
Run No. 7	0.89	1.03	1.06	1.04	0.98	0.76
Run No. 8	0.90	1.01	1.06	1.03	0.96	0.75
Run No. 9	0.98	1.06	1.05	1.02	0.94	0.75
Mean I	0.94	1.04	1.06	1.03	0.96	0.75
dI	5.3%	2.9%	2.8%	1.0%	2.1%	1.3%

P = 9 cm.

D =	16.9	18.5	20.1	21.8	23.4	25.0
Run No. 6	0.84	1.03	1.11	1.12	1.08	0.90
Run No. 7	0.81	0.98	1.10	1.10	1.08	0.96
Run No. 8	0.85	1.03	1.12	1.12	1.08	0.91
Run No. 9	0.78	0.94	1.06	1.10	1.09	0.98
Mean I	0.82	1.00	1.10	1.11	1.08	0.94
dI	4.9%	6.0%	3.6%	0.9%	0.9%	4.2%

P = 10 cm.

D =	16.9	18.5	20.1	21.8	23.4	25.0
Run No. 6	0.72	0.93	1.09	1.13	1.15	1.06
Run No. 7	0.71	0.92	1.06	1.10	1.13	1.06
Run No. 8	0.72	0.87	1.04	1.06	1.14	1.03
Run No. 9	0.71	0.93	1.07	1.15	1.17	1.08
Mean I	0.72	0.91	1.06	1.11	1.15	1.06
dI	1.4%	4.4%	2.8%	4.5%	0.7%	2.8%

Average dI = 2.9%.

In Table I is given a typical set of data on Burner No. 3. It consists of four complete runs made on different days by two observers. No test for the purity of the acetylene was made. In the process of recharging the generator some air was always introduced into the system. The presence of air in the acetylene is indicated by a blue fuzzy tip of about 2 to 4 mm. at the top of the flame. No photometric measurements were taken until this blue tip had disappeared and a clear white flame was

obtained. In some cases 10 to 12 hours burning was necessary before this condition existed.

In Fig. 2 the data on Burner No. 3 is given in the form of curves plotted with I as ordinates and D as abscissae. From these curves it is evident that for a minimum variation in I (between P = 8 and P = 10) the value of D is 20.1 mm., and in this position a change in pressure of 2 cm. (from P = 8 to P = 10) causes a change of only 2.7 per cent. in I. Since P

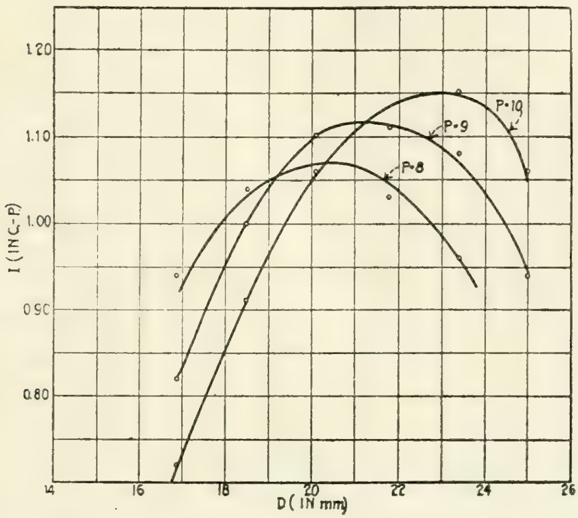

Fig. 2.—Variations of candle-power with window height at different gas pressure.

can be easily controlled to 0.2 cm., it is evident that the corresponding variation in I will be so small as to be negligible in any ordinary work. It will also be noted from the curves that for D = 20.1 mm. the best value of the gas pressure, P, is 9 cm. For if the values of I at the point D = 20.1 be plotted against gas pressure, P, it will be seen that the flattest part of the curve occurs at a point where the value of P is 9 cm. Hence for a minimum variation in I due to a change in P the value of P is 9 cm. In this way the best values of D and P for operating a given burner were established.

TABLE II.

Burner No. 1.

	D = 14.8	16.4	18.0	19.6	21.2
P = 8............	0.85	0.95	0.98	0.94	0.85
P = 9............	0.77	0.92	0.99	1.02	0.94
P = 10...........	0.68	0.85	1.00	1.05	1.04

TABLE III.

Burner No. 2.

	D = 14	16	18	20	22	23
P = 8............	0.92	1.16	1.25	1.25	1.18	1.08
P = 9............	0.81	1.09	1.22	1.28	1.26	1.19
P = 10...........	0.68	0.94	1.14	1.26	1.30	1.27

TABLE IV.

Burner No. 4.

	D = 13.0	14.5	16.0	17.5	19.0	20.5
P = 8............	0.82	1.01	1.14	1.21	1.19	1.14
P = 9............	0.71	0.90	1.07	1.19	1.26	1.23
P = 10...........	0.60	0.80	1.00	1.15	1.24	1.28

TABLE V.

Burner No. 5.

	D = 16.5	18.1	19.7	21.3	22.9
P = 8............	1.04	10.9	1.07	1.00	0.90
P = 9............	1.03	10.9	1.11	1.08	1.02
P = 10...........	0.96	10.8	1.14	1.12	1.08

TABLE VI.

Burner No. 6.

	D = 12.0	13.7	15.4	17.1	18.8	20.5
P = 8............	0.62	0.80	0.92	1.01	0.99	0.94
P = 9............	0.51	0.74	0.93	1.03	1.05	1.04
P = 10...........	—	0.62	0.80	0.92	1.06	1.08

In Tables II to VI is given summarized data on the other burners tested. Two to six complete runs were made on each burner, the mean of values obtained being given in the tables of data. A set of curves (of which the one shown in Fig. 2 is a typical example) was plotted for each burner. From these curves the best values for D and P were obtained for each burner. These values are given in Table VII, in which the meanings of the symbols used are as follows:

Do = Best value for D (in mm.).
Po = Best value for P (in cm.).
Io = The value of I (in c-p.) when D = Do and P = Po.
A = Per cent. change in Io due to a change in Po of 2 per cent.
H = Height in mm. of window in hood of burner.
Io/H = Intensity in c. p. per mm. of flame.
dI = Per cent. deviation of Io/H from mean all burners.

TABLE VII.

Burner	Do	Po	Io	A	H	Io/H	dI
No. 1	17.6	9	0.98	0.05	2.95	0.332	4.8
No. 2	19.8	9	1.28	0.13	3.50	0.366	4.9
No. 3	20.1	9	1.10	0.18	3.20	0.344	1.2
No. 4	18.3	9	1.24	0.19	3.30	0.376	7.5
No. 5	18.1	9	1.09	0.12	3.23	0.338	3.0
No. 6	17.8	9	1.04	0.19	3.05	0.341	2.1
No. 2, Tip No. 5.....	18.1	9	1.18	0.20	3.50	0.337	3.3
No. 2, Tip No. 6.....	17.9	9	1.23	0.15	3.50	0.351	0.9
Mean				0.15		0.348	3.46

The variations in candle-power shown under Io, Table VII, are not entirely due to differences in the burner tips, but partially to height of window in the various burner hoods. These heights were measured by means of a micrometer microscope and the value of I per mm. of exposed flame (see Table VII) for each burner was computed. As a check upon the determination of the best values of P and D some further measurements were made. The burner tip was removed from burner No. 2 and for it was substituted, one after the other, tips from burners No. 5 and No. 6. Sets of observations were made in each case as before (see Tables VIII and IX), curves plotted and Do and Po determined. The results as shown in Table VII agree very well with those previously obtained for the same burner tips. In Fig. 3 is given a set of curves plotted from the data in Table IX. In this case a wider range in values of D was used than is shown in Fig. 2, and hence this set of curves shows more

completely the relation between I and D for the gas pressures used. An inspection of these curves shows that in the upper part of the flame the variation in I due to a change of gas pressure is much more rapid than in the lower part and that at the point D = 18 mm. this variation is a minimum within the range of pressures employed.

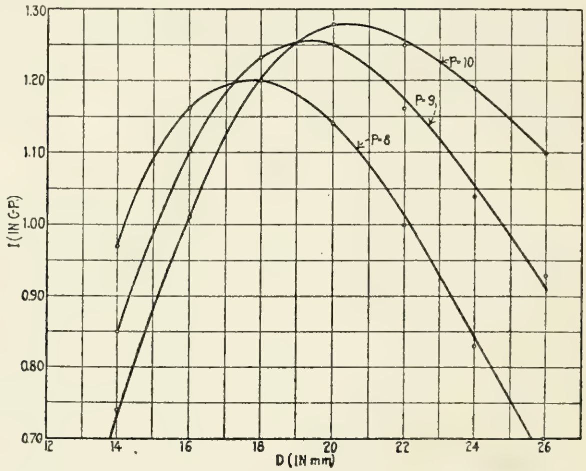

Fig. 3.—Variations of candle-power with window height at different gas pressure.

TABLE VIII.

Burner No. 2 with Tip No. 5.

D =	14.0	16.0	18.0	20.0	22.0	24.0
P = 8	0.93	1.10	1.14	1.08	0.96	0.79
P = 9	0.83	1.04	1.18	1.18	1.10	0.96
P = 10	0.71	0.96	1.12	1.21	1.19	1.13

TABLE IX.

Burner No. 2 with Tip No. 6.

D =	14.0	16.0	18.0	20.0	22.0	24.0	26.0
P = 8	0.97	1.16	1.20	1.14	1.00	0.83	0.70
P = 9	0.85	1.10	1.23	1.25	1.16	1.04	0.93
P = 10	0.74	1.01	1.20	1.28	1.25	1.09	1.10

The quantity A in Table VII was computed in the following way: As a typical example take the data and curves on burner

No. 3, Fig. 2, and Table I. For the best value of D, D = 20.1, the values of I for the various gas pressures were read from the curves. With these values a curve was plotted, Fig. 4, with I as ordinates and P as abscissae. From this curve the value dI_2 corresponding to Po ± 2 per cent. was obtained. This value of dI_2 expressed in per cent. of Io is given under A in Table VII for each burner and is the per cent. variation in Io corresponding to a change in Po of 2 per cent. Since the pressure regulator attached to the generator holds the pressure constant to 2 per cent., the quantity A is the maximum error in I due to a variation in P. Or in case a pressure regulator is not used it is quite easy, by means of a screw actuated pinch cock and a manometer, to set the pressure at 9 cm. within the limits of ± 2 per cent.

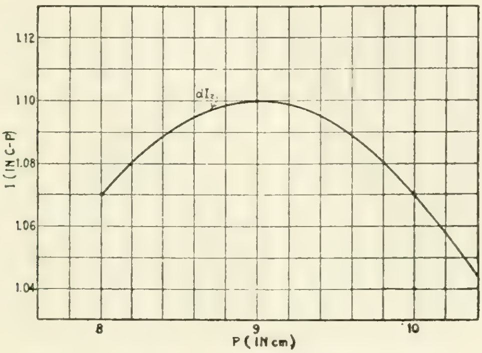

Fig. 4.—Variation of intensity with gas pressure.

In order to determine how soon after the lighting of a burner the intensity reached a steady condition another series of measurements was made. Photometric readings were made rapidly immediately after the lighting of the burner, and the time of each reading from the instant of lighting recorded. Several such runs were made, care being taken that the burner had been allowed to cool to room temperature before lighting. The data so obtained was summarized, and is given as a curve, Fig. 5. This shows that only about 30 sec. is required for the intensity to reach a steady condition.

The effect of humidity upon the intensity was not fully investigated. The humidity of the air in the photometer room was

observed on each day that measurements were being made, but no variations in the intensity corresponding to changes in humidity could be detected. However, in case the burner is to be used in work requiring a very high precision in the intensity of the light source a more complete investigation of this point should be made.

The inner end of the conical shaped window through which the flame was photometered was always close to the flame so that any error due to parallax was inappreciable. Care was always used in placing the burners in position on the photometer that the axis of the burner was in a perpendicular position and that the axis of the photometer passed through the center of the

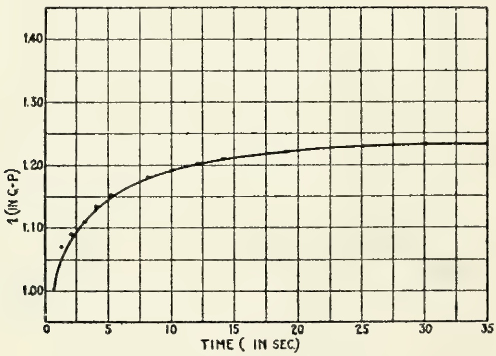

Fig. 5.—Variation of intensity after lighting.

window in the burner hood. In setting a burner up for use after standardizing, a reasonable amount of care should be exercised, but small errors in duplicating position in which it was photometered may be allowed without introducing any appreciable error in the intensity.

The results of the measurements show that such a burner, when properly operated, is sufficiently accurate and reliable for all ordinary purposes. It is not a reproducible standard, but when properly adjusted and standardized makes a very serviceable secondary working standard, giving a good quality of whiteness and constant intensity with little attention on the part of the operator. It has the advantage over an electric incandescent standard lamp that the equipment necessary to operate and to

control the intensity to the necessary precision is much cheaper to install and simpler to operate. The only apparatus necessary to control the intensity is a simple water manometer, while with the electric standard some form of potentiometer is usually necessary to obtain the required precision.

These burners have been in daily use in the laboratory during the past year and have proven very satisfactory. In use on the sensitometers the burner is placed in a large, well ventilated box made of sheet iron, so that the flame is well shielded from air currents. These burners, although designed primarily for use in photographic sensitometry, have been found to be very useful as working standards in other laboratory and testing work where a light source of constant intensity and of known spectral quality is required.

The advantages of this standard source may be summed up as follows: Constant intensity, light of good quality, accurately known spectral energy distribution, simplicity of apparatus required for operation, and the small amount of attention necessary to keep in adjustment.

There are still some points in regard to this type of burner that it would be of interest to investigate and the author hopes at an early date to do something further along this line. As was mentioned before in this paper, the effect of humidity should be precisely determined also that of atmospheric pressure, for these factors must be taken into account in the case of other flame standards such as the pentane lamp, when extreme precision is desired. The relation between the volume of gas consumed, the volume of air mixed with the gas in the burner tip, and the resulting flame intensity should be determined. It seems quite possible that if all the factors affecting the intensity were carefully analyzed that a primary standard of higher precision than any of those existing at present might be produced.

The author here wishes to acknowledge his indebtedness to Mr. M. B. Hodgson for his valuable assistance rendered in making the photometric measurements and in carrying out the experimental work of this investigation.

DISCUSSION.

MR. E. L. CLARK: I am very much interested to hear that another standard light has been developed for photometric work.

I am especially interested in the fact that a diaphragm is used to select the light from a definite and uniform portion of the flame.

While visiting the Bureau of Standards in 1910 when they were working on the pentane lamp, I remember observing that the flames on their lamps fluctuated more or less at their extremities but the body of the flame appeared very steady. I asked Dr. Rosa why they did not place a screen in front of the uniform portion of the light and use that as a standard. He replied to the effect that the parallax error due to working at different distances, was so great as to make such a scheme undesirable.

I would like to have Mr. Jones state the magnitude of the parallax error in case of his lamp. Of course if the lamp were used at a fixed distance from the sight box, this error would not enter in, but in a great deal of photometric work the distance between the standard and the sight box is varied, and a knowledge of the error thereby introduced is essential.

DR. C. H. SHARP: I am very much interested in seeing this proposition for an acetylene standard come up again. It shows that there must be a good deal of merit in it. Soon after acetylene first came into prominence as a product of the reaction of water upon calcium carbide, it was proposed by a French physicist to produce a primary standard by a jet of acetylene issuing from a capillary tube and burning with a given height of flame; he claimed to get very good results as far as reproducibility was concerned, but the thing never seemed to have gone any further. Dr. Nichols has used an acetylene flame a great deal, particularly as a standard of color in spectrophotometric measurements. In the early days of acetylene, I formed the very ambitious project of making a flame standard in which the flame should be unaffected by atmospheric conditions. I constructed a burner in which a little circular jet of acetylene was surrounded by a mantle of pure oxygen. It is unnecessary to say that it gave a pretty bright flame; in fact, the color of that acetylene flame was

about the same as the color of the crater of the carbon arc, and under given conditions it was satisfactorily constant and steady. I allowed the light from this flame to pass out through a horizontal slit similar to the one in this standard, and attempted to control it by measuring the pressure of the acetylene and also of the oxygen, but the thing was too complicated and I had to give it up as a practical matter. I have always been sorry since that I did not put that jet of oxygen inside the jet of acetylene and discover oxyacetylene welding or something of that kind that I might have made some money out of. It is very interesting to see this proposition coming up again, and the way it is being carried out impresses me as being a very hopeful one. I think we would be instructed if we could hear from Mr. Jones what he means numerically by saying that it comes back to the same thing day after day. I think also it would be interesting to know how he generates his acetylene because upon the method of generation as well as upon the purity of materials, the purity of gas depends to some extent, and it is well known that if the gas is generated under conditions in which a high temperature is reached during the process, the gas may be polymerized. Some of the carbon is thrown down and a less rich gas results, which must necessarily give a flame of lower luminosity.

Dr. H. C. Chapin: A diaphragm has been used in a similar fashion over a carbon arc by Forrest (Electrician, London, Aug. 8, 1913). He employed the center of the positive crater as light source. To get unobstructed emission from this and to steady the arc he used two negatives, each at an angle of 100 deg. with the positive and in the same plane.

Mr. S. L. E. Rose: I am interested in this light source, especially if it can be used as a primary standard; its use as a working standard is not as great to me as to the author, perhaps on account of the differences in our work. It may be particularly adapted to his work, but he makes rather a general statement "for practical use in the laboratory and testing work." It seems to me there is nothing better at the present time than the incandescent electric standard for all general photometric work. This is especially true in a constant radius photometer where it is necessary to move the working standard source back and forth on

a track. In this case a flame standard is practically out of the question on account of its susceptibility to air currents.

Mr. C. W. Jordan: In my opinion one of the most promising factors in the use of an acetylene flame for a standard light source is the possibility of reproducing the gas chemically pure at all times. This can be accomplished by using chemically pure calcium carbide and distilled water in a properly designed generator, provided with means for absorbing the dissolved gases of the water liberated after combination of the latter with the calcium carbide.

The only other flame standard consuming a fuel which can be exactly reproduced is a Hefner standard. The objections to its use, however, are numerous, being of low intensity, very reddish color and affected by slight air currents.

Mr. F. K. Richtmyer (Communicated): This field of investigation is a particularly attractive one, for as Mr. Jones points out, the working photometrist finds serious objections of one kind or another with each of the now available standards. The work described by Mr. Jones seems to indicate that the proposed acetylene standard has many points in its favor.

It seems to me, however, that one point, which is given only a passing comment should be investigated much more thoroughly before the new standard is ready for use. I refer to what Mr. Jones calls the "parallax error." It is assumed that since the 3 x 10 mm. opening is "very close" to the flame errors due to this source are reduced to a minimum and are therefore negligible. This does not necessarily follow, for this factor is determined not by the distance from the opening to the flame, but by the ratio of this distance to the distance between the opening and the photometer. On account of the small candle-power of the proposed standard, this latter distance will be, in most cases small. Furthermore, the distance between the opening and the far side of the flame is not small, and will vary from time to time unless the metal hood is very accurately set in place each time and is vertical.

For this reason it is difficult to see why the cylindrical flame has any advantages over the flat flame provided the flat flame be operated with the same care as the cylindrical one.

Mr. L. A. Jones (In reply): In considering the errors due to parallax it is necessary to deal with two types: (*a*) those arising from variations in the distance between the photometer screen and the source and (*b*) those arising from failure to set the burner in the proper position with respect to the photometric axis. In regard to the first type no data are at hand. All the measurements given in this paper were made with the burner at a distance of approximately 35 cm. from photometer screen. However, it would be quite easy to compute from the dimensions of the burner and flame the magnitude of this error for any variation in distance. In the second case four factors occur; (1) departure from the photometric axis in the horizontal direction, (2) departure in the vertical direction, (3) incorrect orientation of the burner about its axis, and (4) error in placing the axis of the burner perpendicular to the photometric axis. It is evident that no change of intensity will result from (1) and (3) if the height of the window is uniform throughout its length. This has been verified by experiment. The factors (2) and (4) are of the same nature, a departure from the photometric axis in the perpendicular direction being equivalent to a lack of perpendicularity of the burner axis to the photometric axis. In order to test the change in intensity due to these causes the axis of the burner was displaced by about 8 deg. from the proper position. The resulting change of intensity was less than 1 per cent.

As was indicated in the paper this work was carried out not with the intention of producing a primary standard but for the purpose of obtaining a good reliable secondary or working standard for certain purposes.

The gas was generated in a water to carbide generator. Ordinary commercial carbide was used. We made no attempt to produce chemically pure acetylene gas.

In regard to Dr. Sharp's question as to the intensity from day to day: The values obtained from day to day on a given burner vary as a rule less than 2 per cent. Thus a burner will measure from 1.18 to 1.20 day after day. As was mentioned in the paper air was introduced into the generator when recharging, the presence of which was indicated by a blue fuzzy tip on the flame. While this exists the intensity is 4 to 5 per cent. lower than the

normal value, but after the flame clears up, the intensity comes back to within 1 or 2 per cent. of its previous value. That is the maximum variation observed after the flame has become clear from day to day and week to week.

THE CHAIRMAN: As measured against what?

MR. JONES: Measured against a one and a quarter watt standard tungsten lamp.

THE CHAIRMAN: Well controlled?

MR. JONES: Oh yes, we control by pententiometer methods. We obtain our standard lamps, some from the National Physical Laboratory and some from the Bureau of Standards and operate them from a storage battery which carries no other load. We have had no trouble from carbonization of the tips. We use a purifier to remove the phosphine and other impurities that may be present. We have used 4 or 5 kinds of purifiers made up by different formulae; I cannot give you those just at present, but there has been no variation in intensity due to a change in the kind of purifier. The use that we have for these burners is on our sensitometers that we use for determining plate speeds. We are using 2 or 3 of these constantly and I think undoubtedly they are much simpler to operate than an incandescent standard.

All that is necessary for a day's work is to light the burner and set the gas pressure to the proper value. The apparatus necessary for the control costs but a few cents, being a simple water manometer and a screw pinch cock. In using electric standards we would have to have a set up at each sensitometer for the precise measurement of current and voltage. This would be expensive. Our standards burn on the average of 6 hours per day or 36 hours per week. At this rate an electric standard would not last long, and would require much more attention to keep it in proper condition. For these reasons the acetylene standard is much more satisfactory for our purposes.

THE CHAIRMAN: What has been the life of these?

MR. JONES: We have been using one burner for about 2 years now and it seems to be as good as ever; there has been no change in the intensity.

MR. S. L. E. ROSE: How often do you have to check them?

Mr. Jones: At first, when we began using them, we checked them every week but did not find any appreciable variation from time to time; so now we only check them about every 2 months.

In regard to the flicker being produced by the re-entrant window—we do not find any trace of that whatever. This burner is put inside of a small well ventilated sheet iron lamp house, partially to shield it from air currents and partially to make it possible to work photographic goods in the same room with the lighted burner.

Mr. Rose: Do you move your standard around or is the standard stationary?

Mr. Jones: No; it is stationary, and when we are measuring on the photometer, it is in a stationary position also.

In regard to the size of the window—that was measured on a micrometer microscope, and the accuracy there I should say was about something like two or three thousandths of a millimeter in measuring the height of window.

We kept a record of the humidity over a period of 3 or 4 weeks while doing the work on the burner and could not detect any systematic variation at all with humidity, although the room humidity varied quite considerably during the time, and of course the barometric pressure may have varied. We obtained no indication whatever of any humidity effect. I do not say there is no humidity effect there.

CHARACTERISTIC EQUATIONS OF TUNGSTEN FILAMENT LAMPS AND THEIR APPLICATION IN HETEROCHROMATIC PHOTOMETRY.*

G. W. MIDDLEKAUFF AND J. F. SKOGLAND.

Synopsis: This paper gives an account of the difficulties experienced at the Bureau of Standards in calibrating lamps differing in color from the 4-w. p. c. carbon primary standards which maintain the international candle. It also proposes a method of overcoming the difficulties by the use of tungsten filament secondary standards. These are measured at a match in color directly in terms of the primary standards, and their candle-power values at any other color are determined from the corresponding measured voltages. This is done by the use of characteristic equations which the authors have derived from the results of measurements of tungsten lamps of various sizes and makes. In determining these equations the difficulties due to color difference are dealt with once for all. Tables of values computed by means of these equations are given for use in practical photometry.

I. INTRODUCTION.

This investigation was carried out at the Bureau of Standards with a view to finding a more satisfactory method than those at present in vogue for overcoming the difficulties due to color difference when lamps of high efficiency are to be compared with the carbon primary standards. In order that the application of characteristic equations in this connection may be fully understood, we shall first give a brief description of the character of the standard photometric work of the Bureau, the methods employed, and the principal difficulties encountered.

II. STANDARD PHOTOMETRIC WORK AT THE BUREAU OF STANDARDS.

1. *The Primary Photometric Standards.*—The photometric standards by means of which the international candle is maintained at the Bureau of Standards are a group of carbon filament incandescent lamps operated at an efficiency of 4 w. p. m. h. c. On account of photometric difficulties which are involved in com-

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

paring lights of different color and which increase as the color difference increases, it is fortunate that these primary standards occupy a position at about the middle of the range of color of lamps now used as secondary and working standards, being blue in comparison with the Hefner and other flame standards and red in comparison with tungsten lamps when operated at or near normal efficiency. Although the greatest color difference from the primary standards is small in comparison with that met with in commercial photometry, nevertheless it is sufficient to be very troublesome in standard photometry where the greatest accuracy is required.

2. *Classes of Lamps Submitted for Standardization.*—In general there are two classes of lamps submitted to the Bureau of Standards for certification, (a) flame lamps, of which practically all are pentane and (b) electric incandescent lamps, of which during the past year one third were carbon and two thirds tungsten.

(a) *Flame Lamps.*—Although different forms of flame lamps have been recognized as primary standards (for example, the Carcel in France, the Hefner in Germany, and the pentane in England) none of them is now considered entirely satisfactory for this purpose.[1] Though made and used according to official specifications, individual lamps differ among themselves by amounts considerably greater than the errors of photometric measurement. Incandescent lamps, on the other hand, when operated at a definite voltage at which they have been standardized in terms of a light unit agreed upon, will maintain that unit constant with an accuracy far above that which is possible with flame standards. With so much in favor of incandescent lamps, it is perfectly reasonable that they, in preference to any of the present so-called primary flame standards, should be chosen to maintain the international candle constant, at least until a lamp appears the value of which can be satisfactorily reproduced from specifications. Accordingly in this country, the real primary standard is a group of incandescent lamps, and the various flame standards which are assigned values by comparison with the pri-

[1] Rosa and Crittenden, "Flame Standards in Photometry" *Bull. Bureau of Standards*, vol. x, p. 557.

mary carbon standards have become secondary standards, and their specifications are practically ignored except by the makers.

In the photometry of pentane lamps, the measurements are made directly in terms of carbon working standards operating at a low efficiency (about 7 w. p. c.) so as to match the pentane flame in color. As this color is practically the same for all pentane lamps, and remains constant under normal working conditions, only one group of electric working standards is required and the color difference involved in checking them in terms of the primary standards is the same from time to time. In so far as the preparation and maintenance of working standards is concerned, the standardization of pentane lamps is therefore simple in comparison with that of electric incandescent lamps.

(b) *Electric Incandescent Lamps.*—On account of the great flexibility as to color of the incandescent lamp, especially of the tungsten lamp, when supplied with current at different voltages, the range of color through which it may be used as a standard extends from the dull red of initial incandescence to comparative blue at normal efficiency. Even normal efficiency is not a fixed value but has been and is still steadily increasing with improvements in manufacture. The Bureau, therefore, as custodian of the primary standards must be in a position to calibrate incandescent lamps at a large number of efficiencies, and hence a single group, or even a number of groups, of working standards, each group of some definite color, cannot meet the desired condition of color match with any given lamp that may be submitted for test.

It is obvious therefore that, with the exception of carbon lamps at 4 w. p. c., the standardization of practically every lamp submitted involves, either directly or indirectly, a color difference in the photometric measurements.

3. *Difficulties Due to Color Difference.*—Comparison of lamps of the same color involves no special difficulties and comparatively little experience is required to enable an observer to produce results of considerable accuracy. But when a color difference exists, even observers of experience do not agree in their photometric measurements, due principally to two causes,

(1) difference in color vision and (2) difference in judgment as to what constitutes a match in intensity, thus rendering it difficult for an individual to repeat even his own observations with the precision possible when there is a color match. Hence to establish standards, it is not only necessary to have observers of normal color vision but also to obtain a very large number of readings by experienced observers who have learned to fix and maintain a suitable criterion so that they can obtain consistent results at different times.

III. METHODS OF HETEROCHROMATIC PHOTOMETRY.

In the photometry of differently colored lights at least four methods have been used, *viz.*, visual acuity, critical frequency, equality of brightness, and flicker. Of these, only the last two mentioned are sufficiently sensitive for the accuracy required in precision work.[2] In the experience of the Bureau of Standards more consistent results have been obtained by the equality of brightness than by the flicker method and for this reason the Lummer-Brodhun contrast photometer, which makes use of the equality of brightness principle, has been used for all photometric work both for lights of the same color and of different color.

IV. ELIMINATION OF COLOR DIFFERENCE IN ROUTINE WORK.

In the Bureau's regular routine work of standardizing lamps of high efficiency (*i. e.*, blue in comparison with carbon standards) the measurements, so far as is possible, are made with color match obtained either by the use of blue glass screens placed in the path of the light from the carbon working standards or by the use of tungsten working standards of approximately the color of the lamps to be measured. The latter may be a group of standards each operated at a single voltage (or color) or a group whose candle-power values are known through a considerable range of color. However, it is the common practise, especially when important standards are submitted, to make measurements in terms of all three groups.

1. *Use of Color Screens.*—Obviously either red or blue screens

[2] Ives, H. E.; *Phil. Mag.*, vol. 24, p. 156, 1912.

of the proper spectral absorption may be used to eliminate color difference. Up to the present, however, red screens of sufficient transparency have not been obtainable, hence all color matching of test lamps with the primary standards has been done with blue glasses which can be obtained with almost any desired degree of color absorption and very uniform throughout.

2. *Use of Secondary Standards.*—Evidently the best way of eliminating color difference in the photometry of any light source is by the use of a standard of the same kind. Hence it is an advantage to use electric incandescent standards when measuring lamps of this kind. Fortunately the tungsten lamp is so flexible as to color adjustment that it can be made to match all incandescent lamps, regardless of the material of the filament. Further than this, it can be made to match, at least very approximately, the color of every flame lamp used as a standard. It is therefore an ideal working standard in heterochromatic photometry. It has an advantage over the use of color screens in that it will match the test lamps at whatever efficiency they may fall, but it has the disadvantage of being less durable.

Although both methods are satisfactory in the elimination of color difference in routine work, both defer rather than dispose of the difficulties which must be met in the calibration of the screens and the standardization of the lamps. As secondary tungsten standards are usually standardized by the use of glass screens, the problem of stepping from one color to another reduces itself to the calibration of the screens.

V. CALIBRATION OF COLOR SCREENS.

The calibration of color screens introduces deviations in observed values fully as great as those which obtain in the direct comparison of lamps of different color. This renders the derivation of reliable values a more difficult matter than would at first appear. Even after a reliable value is obtained the advantage of measurements at a color match is not fully realized because the range in efficiency through which a given screen eliminates color difference is rather narrow. For the best results a different screen should be used for each efficiency, and the calibration of each screen means that the same difficulties must again be encountered. It was with a view of finding a method of reducing both

the errors and the amount of labor involved in these calibrations that this investigation was undertaken.

1. *Old Method, Involving Color Difference.*—The most direct method of determining the percentage transmission (or transmission coefficient) of a color screen for use with a source of 4-w. p. c.-carbon color is as follows. The photometer is arranged as for the ordinary comparison of two lamps A and B, of which A is adjusted to 4-w. p. c.-carbon color. The screen is placed at the side of the photometer head in the path of the light from this lamp, and B is adjusted to match the transmitted light in color. A photometric setting is then made with the screen in position and another with it removed. The ratio of the first setting to the second gives the coefficient of the screen independently of the values of A and B. The test may be varied by adjusting B to color match A when the screen is removed, or B may be adjusted to a color anywhere between those of the direct and transmitted light from A. In every case, however, at least one of the two settings required must be made with a color difference, thus involving all the difficulties and uncertainties of the photometry of differently colored lights.

In the calibration of the screen it is important that lamp A be of the same color as the light source with which the screen is to be used, otherwise the coefficient will have a different value depending upon the incident light.

2. *Proposed Method, Using Voltage–Candle-power Relation.*—In order to avoid measurements involving color difference when making such calibrations the following method is proposed. Both sources A and B are tungsten lamps. A is first adjusted in voltage (to about 3.1 w. p. c.) to match 4-w. p. c.-carbon color and B is adjusted as before, that is, to a color-match with the light transmitted by the screen. After making a photometric setting, the screen is removed and, with B constant, A is increased in voltage until it matches B in color, and a second setting is made. Calling the settings S_1 and S_2 and the two candle-power values of A, C_1 and C_2, respectively, the coefficient of transmission is $T = \frac{S_1}{S_2} \cdot \frac{C_2}{C_1}$. As both settings are made with a color match, all the difficulties involved in the method first given above are

eliminated, close agreement among different observers results, and T is determined with comparatively little labor.

This method, however, assumes that the ratio $\frac{C_2}{C_1}$ has been accurately determined, which can be easily done in terms of the corresponding observed voltages, provided the voltage–candle-power relation for the lamp is known with sufficient accuracy. As the method promised to avoid in the future an enormous amount of labor and to give results of considerable accuracy, the conclusion was reached that it would be advisable to determine the relation over a considerable range of voltage and to calculate, if possible, an equation from which this characteristic could be reproduced.

VI. MEASUREMENT OF LAMPS FOR CHARACTERISTIC RELATIONS.

1. *The Lamps Investigated.*—The group first investigated was composed of seven 60-watt, 110-volt tungsten standards whose constancy had been well established. The filaments of these lamps were 'formed' drawn wire comprising four hairpin loops, with legs welded in series to the bottom radial anchors. The forming process having removed the elasticity at the bend, the loop retains its form without varying the pressure on the top supports. The latter were light molybdenum wires each with a helical coil between the loop supporting the filament and the end fused into the central hub. This arrangement gives an elastic mount resulting in ready adaptation to expansion and contraction of filament without sag and a steady value of current is reached very soon after the lamp is placed in circuit.

2. *The Standards Employed.*—As the lamps were to be run at twelve voltages corresponding to efficiencies ranging from about 3.8 to 1.1 w. p. c., it was decided to divide the measurements so as to secure values in terms of carbon and tungsten working standards with an approximately equal range of color against each group of standards.

Consequently from the lowest voltage to that corresponding to about 2.0 w. p. c., carbon working standards were used. Measurements at higher voltages were made against tungsten working standards. It is evident therefore that there was a considerable

range in color between standards and test lamps running from reddish (relatively low efficiency) to bluish (relatively high efficiency) against each group of standards. But as the average results of the five observers who made the measurements on these lamps had been found to be the same as that of a much larger group of equally experienced observers when a color difference was involved in the photometric measurements, it is believed that the results here obtained are such as would be obtained by an average or normal eye.

(a) *Carbon Standards.*—These standards operate at the same color as the primary standards with which they are kept in check by frequent intercomparisons. When matching the carbon standards in color the tungsten lamps operate at about 3.1 w. p. c.

(b) *Tungsten Standards.*—The normal operating efficiency of these standards is approximately 1.5 w. p. c. Their candle-power and current values have been indirectly verified by the National Physical Laboratory of England, as agreement in candle-power and current values on several groups of lamps (which the tungsten working standards reproduce) was obtained between the National Physical Laboratory and the Bureau as the result of careful measurements by each laboratory, several different methods having been employed.

3. *Apparatus.*—All measurements of candle-power were made on a double photometer, thus affording a valuable check of one observer against the other. The individual settings were recorded on a chart by a special printing device auxiliary to the photometer. By this method of recording the observer is entirely unprejudiced in his settings. Voltage and current were measured simultaneously by means of two potentiometers.

4. *Observed Values.*—In order to avoid a repetition of tables the observed and computed values for these lamps are given together in Tables III and IV to which reference should be made at this point. The two lamps (Nos. 2658 and 2660) exhibited in Table III were selected as best representing the group of seven. The observed values given for each lamp are the means of all values obtained by the various observers, there being an average of about seven at each voltage. Each observed value is the

average of from 10 to 40 individual photometric settings represented by a corresponding number of points on the record chart.

5. *Accuracy of the Measurements.*—Of a total of about 680 individual observed values, about 5 per cent. having comparatively large deviations from the mean were discarded for reasons considered justifiable. After this procedure the mean of the remaining observations at each voltage for each lamp was accepted as the observed value and is so designated in what follows.

At the individual voltages the deviation from the accepted mean observed value ranged from 0.7 to 0.2 per cent., the mean deviation being 0.45 per cent. Deviations at color match with carbon and with tungsten standards were approximately equal and were very close to the mean value of 0.45 per cent.

VII. CHARACTERISTIC EQUATIONS.

1. *Form of Equations Previously Used.*—Earlier attempts at characteristic equations have been of the constant exponent form,[3] $y = ax^b$, the range of application having been usually admitted to be comparatively limited; or of the form[4] $y = ax^b [1 + cx + dx^2]$ in which x is a variable ratio (*e. g.*, voltage ratio) and a, b, c and d are constants. The second equation, though considerably more general than the first, does not fit the observed values herein given with the accuracy required for the present purpose. In actual practise, however, the method most generally followed has been to draw curves through observed values without reference to their equations. A modification of this method[5] involves the use of the slope of the characteristics as exponents.

2. *Form of Equation Adopted by the Authors.*—As a logarithmic graph of the observed values of voltage and candle-power obtained in this investigation indicated a smooth curve for each lamp, an empirical equation of the form $y = Ax^2 + Bx + C$ was assumed, in which $y =$ log. candle-power and $x =$ log. volts, A, B, and C being constants. This is equivalent to the assumption that the rate of change of the slope is constant and

[3] Merrill; *Trans. A. I. E. E.*, vol. 29, 1910, p. 959.

[4] Cady; *Elec. Rev. & West. Elec.*, vol. 59, p. 1092, 1911.

[5] Edwards; *Gen. Elec. Review*, March, 1914, p. 283.

equal to 2A; *i. e.*, $\frac{d^2y}{dx^2} = 2A$. This is the first proposal of an equation of this form although it is the form logically required to produce a smooth curve on logarithmic paper.

The slope, $\frac{dy}{dx} = 2Ax + B$, corresponds to the differential coefficient mentioned by Cady[6] and its evaluation gives a factor which may be used for correction from observed values to other values within a small range.

The equation expressing the relation of volts to watts was found to be of the same form, y indicating log. watts in this case.

Since log. w. p. c. = log. watts — log. cp., the constants in the equation expressing the relation of volts to w. p. c. are obtained by subtracting those of the voltage–candle-power equation from those of the voltage–wattage equation. Similarly, since log. amperes = log. watts — log. volts, the equation expressing the relation of volts to amperes is of the form $y = Ax^2 + (B - 1)x + C$, the constants A, B, C having the same values, respectively, as in the voltage–wattage equation. It is therefore necessary to solve only two equations expressing the relations, voltage to candle-power, and voltage to wattage (or voltage to current).

The equations expressing these two relations were then solved for each lamp of the group by the method of least squares, Gauss' method of substitution and successive reduction being employed, the results giving A, B, and C, respectively, for each equation, and from these equations all the others were derived.

As the slope of the curve represented by these equations is a function of the w. p. c., it is evident that either to compare similar curves of the various lamps or to determine a mean value of each variable for the group, it is necessary to choose some value of w. p. c. as a basis and to express the values of the dependent variables in terms of (or percentages of) the values corresponding to the chosen basis. For the sake of brevity the w. p. c. basis and the corresponding values of all the variables will be hereafter referred to as normal values.

It is entirely immaterial what efficiency is chosen as normal,

[6] *Elec. Rev. & West. Elec.*, vol. 59. p. 1091.

but for this group of curves 1.20 w. p. c. was found most convenient and for this reason it was selected. As will be shown later, it is a simple matter to change to any other desired normal efficiency.

By assuming the values of all variables, except w. p. c., to be unity at normal efficiency (1.20 w. p. c.) the constant C disappears from every equation except the one for w. p. c. evaluation, where it has the value 0.07918 (*i. e.*, log. 1.20). In the equations given below, x and y each represents the logarithm of the ratio of the corresponding variable to its normal value, except that in the voltage–w. p. c. equation y represents the actual w. p. c.

3. *Table of Equations.*—The fundamental equations and the most important equations derived from them are given in Table I. In these equations,

$$x = \text{log. voltage ratio,}$$
$$y_1 = \text{log. actual w. p. c.,}$$
$$y_2 = \text{log. candle-power ratio,}$$
$$y_3 = \text{log. wattage ratio,}$$
$$y_4 = \text{log. current ratio,}$$

and the conditional relation among these quantities is that

$$x = y_2 = y_3 = y_4 = \text{log. } 1 = 0 \text{ when } y_1 = \text{log. } 1.20 = 0.07918.$$

TABLE I.—CHARACTERISTIC EQUATIONS.

1. $y_1 = 0.918x^2 - 2.009x + 0.07918$
2. $y_2 = -0.946x^2 + 3.592x$
3. $y_3 = -0.028x^2 + 1.583x$
4. $y_4 = -0.028x^2 + 0.583x$

Equations derived from the above.

1a. $x = 1.09490 - 1.0439\sqrt{1.02073 + y_1}$

2a. $x = 1.89870 - 1.0282\sqrt{3.41000 - y_2}$

5 . $y_1 = 2.88028 - 1.5169\sqrt{3.41000 - y_2} - 0.970y_2$

5a. $y_2 = 1.74682 - 1.5878\sqrt{1.02073 + y_1} - 1.031y_1$

These derived equations are obtained as follows: 1a and 2a from 1 and 2, respectively, by expressing x in terms of the corresponding y; 5 from 1 and 2 by the elimination of x; and 5a from 5 by expressing y_2 in terms of y_1. In many problems the

equations expressed in this form will be found more convenient than in the original form.

Since equations 1 to 4 are quadratics there are two values of x which satisfy each. For example, in equation 1a, $x = 1.09490 \pm 1.0439 \sqrt{1.02073 + y_1}$. The conditional relation that $x = y = 0$ when $y_1 = 0.07918$ leads to the selection of the value in which the last term is negative. Similar reasoning applies to the other three equations.

4. *Examples Illustrating Use of the Equations.*—The first step in the solution of every problem is to determine from the observed values of voltage, candle-power, and w. p. c., the corresponding values at normal efficiency (1.20 w. p. c.). This is done by substituting the values of log. observed w. p. c. in equations 1a and 5a, obtaining from 1a the ratio of the observed voltage to the voltage corresponding to normal w. p. c., and from 5a the ratio of the observed candle-power to the candle-power corresponding to normal. The numerical values of voltage and candle-power at normal are obtained by dividing the observed values by the ratios just found. The value of watts at normal equals the product of normal candle-power by 1.20.

As an example to illustrate the use of the equations, let us take the observed values corresponding to the first and second voltages of lamp No. 2658, as given in Table III, *viz.*,

1	65.0 volts,	6.64 cp.,	3.694 w. p. c.
2	70.7 "	9.28 "	3.021 "

Substituting in equation 1a the logs of these two values of w. p. c., in succession, we have the following:

1. log. volt ratio $= 1.09490 - 1.0439 \sqrt{1.02073 + 0.56750}$.
$= 1.09490 - 1.31557 = 9.77933 - 10$.
Or volt ratio $= 0.6016 = 60.16$ per cent.
That is, 65.0 volts $= 60.16$ per cent. of normal voltage.
Therefore normal voltage $= 65 \div 0.6016 = 108.04$.

2. log. volt ratio $= 1.09490 - 1.0439 \sqrt{1.02073 + 0.48015}$.
$= 9.81602 - 10$.
Or volt ratio $= 0.6546 = 65.46$ per cent.
Therefore normal voltage $= 70.7 \div 0.6546 = 108.00$.

Now substituting the value of log. w. p. c. in equation 5a we have the following:

1. log. cp. ratio $= 1.74682 - 1.5878\sqrt{1.02073 + 0.56750}$
$- 1.031 \times 0.56750.$
$= 1.74682 - 2.00101 - 0.58510.$
$= 9.16071 - 10.$

Or cp. ratio = 14.478 per cent.

Therefore normal cp. $= 6.64 \div 0.14478 = 45.87.$

2. log. cp. ratio $= 1.74682 - 1.5878\sqrt{1.02073 + 0.48015}$
$- 1.031 \times 0.48015.$
$= 9.30658 - 10.$

Or cp. ratio = 20.256 per cent.

Therefore normal cp. $= 9.28 \div 0.20256 = 45.81.$

The means of these results give the following normal values; voltage 108.02, candle-power 45.84, watts 55.01 ($= 45.84 \times 1.20$). With the above value of voltage (108.02) as basis, computed values for all the variables corresponding to any voltage ratio to normal are found by substituting the log. of this ratio in equations 1–4. Values corresponding to 65 volts and 70.7 volts are computed as follows. The ratios of these voltages to normal (108.02) are 0.6017 and 0.6545, respectively. Substituting the log. of these ratios in equation 2, we have

1. log. cp. ratio $= -0.946\,(9.77938 - 10)^2$
$+ 3.592\,(9.77938 - 10).$
$= -0.04604 - 0.79247 = -0.83851$
$= 9.16149 - 10.$

Or cp. ratio = 0.14504 = 14.504 per cent.

Therefore computed cp. at 65 V $= 45.84 \times 0.14504 = 6.65.$

2. log. cp. ratio $= -0.946\,(9.81591 - 10)^2$
$+ 3.592\,(9.81591 - 10).$
$= -0.03206 - 0.66126 = -0.69332$
$= 9.30668 - 10.$

Or cp. ratio = 20.262 per cent.

Therefore computed cp. at 70.7 V $= 45.84 \times 0.20262 = 9.29.$

These examples are sufficient to show the method of solution. Although the equations are simple and easy to handle their use involves comparatively long and tedious computations.

VIII. TABLES OF PERCENTAGE VALUES.

In order to avoid the computations just referred to a set of Tables (XV–XVIII) has been calculated from which, with the

use of an ordinary slide rule, the various factors may be read off directly.

As these tables will be referred to in what follows, a brief explanation of their use is given here.

Normal values for voltage and candle-power are obtained from the double Table XV which takes the place of equations 1a and 5a. Observed w. p. c. in steps of 0.1 and intermediate steps of 0.01 are given, respectively, at the top and left margin of the table, and corresponding to these, in the body of the table are given percentage factors by which observed values of voltage and candle-power respectively are to be multiplied to reduce them to values they would have at normal efficiency. These percentage factors are the reciprocals of those which are obtained in a similar reduction by means of equations 1a and 5a. In other words, the equations referred to give divisors, while Table XV gives multipliers to be applied to the observed values to reduce them to normal. The table was thus arranged in order to make it consistent with the other tables, the figures in the body of each table being used as multipliers in every case when per cent. values are given.

Having obtained the value for normal candle-power, the value for normal watts is derived by multiplying by 1.20. Knowing the normal values for all the variables, the values corresponding to any percentage of normal volts may then be read from one of the other tables depending upon the variable considered. Practical use of the tables is made in the following section.

IX. COMPARISON OF COMPUTED AND OBSERVED VALUES.

In order to show the method of using the tables, computations from observed values on lamp No. 2658 will be continued. In Table XV corresponding to the last seven values of observed w. p. c. the following percentage factors are found:

No.	Observed w.p.c.	Percentage factors	
		Voltage	Candle-power
1.	1.921	125.13	228.4
2.	1.754	120.03	195.1
3.	1.556	113.44	158.4
4.	1.402	107.88	131.8
5.	1.274	102.96	111.2
6.	1.204	100.16	100.6
7.	1.118	96.51	88.08

5

Applying these factors to the various values of observed voltage and candle-power we obtain the following values for normal voltage and candle-power.

No.	Observed voltage	Percentage factor	Normal voltage	Observed cp.	Percentage factor	Normal cp.
1.	86.3 ×	125.13 =	107.99	20.06 ×	228.4 =	45.82
2.	90.0 ×	120.03 =	108.03	23.49 ×	195.1 =	45.83
3.	95.0 ×	113.44 =	107.77	28.84 ×	158.4 =	45.68
4.	100.0 ×	107.88 =	107.88	34.74 ×	131.8 =	45.80
5.	105.0 ×	102.96 =	108.11	41.28 ×	111.2 =	45.90
6.	108.0 ×	100.16 =	108.17	45.67 ×	100.6 =	45.94
7.	112.0 ×	96.51 =	108.09	52.12 ×	88.08 =	45.91
		Mean =	108.01		Mean	45.84
		Av. dev. =	0.107		Av. dev. =	0.07
		Per cent. " =	0.10		Per cent. " =	0.15

Normal watts = 45.84 × 1.20 = 55.01

Therefore the mean normal values for this lamp are: cp. 45.84, volts 108.01, watts 55.01.

It will be noticed that the mean normal values for this lamp as found under 4, Sec. VII, by the equations from two observed values at and near color match with 4-w. p. c. carbon standards are identical with those found here from seven observed values. While identical results are not to be expected, the above results show that agreement to about 0.2 per cent. in candle-power and 0.1 per cent. in voltage on the average would be obtained by using any single set of observed values as basis.

The results of a similar computation on lamp No. 2660 are as follows:

TABLE II.

Observed volts	Computed values at 1.20 w. p. c. Candle-power	Volts
86.4	45.35	107.59
90.0	45.34	107.60
95.0	45.35	107.54
100.0	45.38	107.59
105.0	45.56	107.77
108.0	45.64	107.96
111.5	45.31	107.46
Means	45.42	107.65
Av. dev.	0.104	0.131
	0.23%	0.12%

Normal watts = 45.42 × 1.20 = 54.50

With 108.01 and 107.65, respectively, as the values of normal volts for the two lamps considered, computed values for candle-

power, watts and watts per candle at each observed voltage are obtained from Tables XVI, XVII and XVIII, respectively. For example, the computed values for lamp No. 2658 at 65.0 volts are found as follows:

Since 65.0 = 60.18 per cent. of 108.01 volts, we find in the tables corresponding to this per cent. volts the following values:

From Table XVIII 3.690 actual w. p. c., the value required.
" " XVI 14.52 per cent. cp.
" " XVII 44.620 per cent. watts.

$45.84 \times 0.1452 = 6.66$, computed cp. at 65 volts.
$55.01 \times 0.44620 = 24.55$, computed watts at 65 volts.

In this manner computed values corresponding to all the observed voltages are obtained. If the above values are found by means of the equations, the particular ones used are 1, 2 and 3. A comparison of computed and observed values follows:

TABLE III.—Comparison of Computed and Observed Values.

Lamp No. B. S. 2658.

	Candle-power		Watts		Watts per candle	
Volts	Computed	Observed	Computed	Observed	Computed	Observed
65.0	6.66	6.64	24.55	24.53	3.690	3.694
70.7	9.30	9.28	28.07	28.04	3.020	3.021
75.0	11.71	11.76	30.83	30.81	2.634	2.620
80.0	15.03	15.01	34.17	34.15	2.273	2.275
82.0	16.52	16.56	35.53	35.52	2.151	2.145
86.3	20.06	20.06	38.54	38.53	1.921	1.921
90.0	23.49	23.49	41.20	41.19	1.754	1.754
95.0	28.71	28.84	44.88	44.88	1.564	1.556
100.0	34.67	34.74	48.69	48.70	1.404	1.402
105.0	41.40	41.28	52.60	52.61	1.271	1.274
108.0	45.82	45.67	55.00	55.01	1.200	1.204
112.0	52.21	52.12	58.27	58.29	1.116	1.118
	Av. dev., 0.23%		0.04%		0.19%	

Lamp No. B. S. 2660.

	Candle-power		Watts		Watts per candle	
Volts	Computed	Observed	Computed	Observed	Computed	Observed
65.0	6.68	6.67	24.45	24.43	3.661	3.662
70.9	9.43	9.38	28.08	28.06	2.977	2.992
75.0	11.75	11.78	30.71	30.68	2.614	2.605
80.0	15.08	15.05	34.03	34.01	2.257	2.260
82.0	16.57	16.56	35.39	35.37	2.136	2.136
86.4	20.21	20.22	38.46	38.44	1.903	1.901
90.0	23.56	23.59	41.03	41.02	1.742	1.739
95.0	28.81	28.83	44.71	44.70	1.553	1.550
100.0	34.77	34.82	48.49	48.50	1.395	1.393
105.0	41.53	41.41	52.39	52.42	1.262	1.266
108.0	45.96	45.71	54.78	54.79	1.192	1.199
111.5	51.53	51.69	57.62	57.63	1.119	1.115
	Av. dev., 0.23%		0.05%		0.24%	

TABLE IV.—COMPARISON OF COMPUTED AND OBSERVED VALUES.

Mean of the Group of Seven Lamps.

Volts	Candle-power Computed	Candle-power Observed	Deviation, per cent. observed from computed value
65	6.63	6.62	—0.15
70.6	9.18	9.16	—0.22
75	11.66	11.70	+0.34
80	14.96	14.98	+0.13
82	16.45	16.44	—0.06
86.5	20.13	20.17	+0.20
90	23.39	23.41	+0.09
95	28.61	28.67	+0.21
100	34.55	34.62	+0-20
105	41.27	41.20	—0.17
108	45.68	45.43	—0.55
111.8	51.72	51.84	+0.21
		Mean	0.21 %

It should be stated that every lamp of the group was measured at all the voltages given in column 1 of the table with the exception of the 2nd, 6th, and last voltages. These are the means of voltages of the individual lamps, the differences from the mean in every case being less than half a volt. Likewise, the corresponding values of computed and observed candle-power at these voltages are the means of the values for the individual lamps.

A Second Method of Computing Candle-power.—Another method of computing candle-power values is based on the assumption that computed watts equal observed watts. After obtaining values of voltage and candle-power at normal efficiency the voltage ratios are determined and w. p. c. is read directly from Table XVIII. Then computed candle-power equals observed watts divided by computed w. p. c. The method is illustrated by the use of lamp No. 2658, observed values being taken from Table III.

TABLE V.

Voltage	Voltage ratios	1 Watts computed from Table XVII	2 Watts determined from obs. of cur. and voltage	3 W.p.c. computed from Table XVIII	4 Cp. (Col. 2 ÷ Col. 3)	5 Observed cp.
65.0	60.18	24.55	24.53	3.690	6.65	6.64
70.7	65.46	28.07	28.04	3.020	9.30	9.28
75.0	69.44	30.83	30.81	2.634	11.71	11.76
80.0	74.07	34.17	34.15	2.273	15.03	15.01
82.0	75.92	35.53	35.52	2.151	16.52	16.56
86.3	79.90	38.54	38.53	1.921	20.06	20.06
90.0	83.33	41.20	41.19	1.754	23.49	23.49
95.0	87.95	44.88	44.88	1.564	28.70	28.84
100.0	92.58	48.69	48.70	1.404	34.68	34.74
105.0	97.21	52.60	52.61	1.271	41.39	41.28
108.0	99.99	55.00	55.01	1.200	45.83	45.67
112.0	103.69	58.27	58.29	1.116	52.21	52.12
		Av. dev. 0.04%			0.22%	

It is seen from the above that the computed watts are of a degree of accuracy sufficiently high that we may employ the values determined from the observations, computing w. p. c. by Table XVIII, and from the two obtain candle-power by division, *i. e.*, cp. = W ÷ w. p. c. Consequently, Tables XVII and XVIII are the only ones which need to be used in adjustments of this kind.

X. FURTHER VERIFICATION OF THE EQUATIONS.

1. *Application to a Group of Drawn Wire Lamps of Recent Manufacture.*—Although the lamps used in the determination of the constants of the equations were operated at voltages corresponding to efficiencies no higher than 1.1 w. p. c. (because of their value as standards) the results obtained seemed to justify extrapolation to 0.7 w. p. c. However, there arose an opportunity to verify the extrapolated values by a group of lamps submitted for test over this range.

These lamps were manufactured early in 1914 and were not intended for standard purposes. Though there was a slight variation in current, they were remarkably steady for commercial lamps, especially at higher voltages. The computed and observed candle-power values are given in Table VI.

TABLE VI.—COMPARISON OF COMPUTED AND OBSERVED VALUES.
Group of Seven 40-Watt Drawn-Wire Lamps.

Volts	Candle-power Computed	Candle-power Observed	Deviation, per cent. observed from computed value
96	18.26	18.20	—0.33
104	24.51	24.48	—0.12
112	32.05	32.15	+0.31
120	40.97	41.07	+0.24
128	51.37	51.46	+0.18
136	63.33	63.48	—0.24
144	76.91	76.71	—0.26
		Mean	0.24%

W. p. c. range 1.6 to 0.72

The maximum deviation of observed from computed candle-power values of a single lamp of this group at one voltage point was 0.56 per cent.

In order to test fully the accuracy of equation 4, Table I, as applied to these lamps, the following method was used in obtaining ampere readings on three lamps of the group.

A ballast lamp of 40-watt size was set to a desired voltage and this voltage was applied suddenly to the lamp under test while rotating approximately 120 r. p. m.

The test lamp, still rotating, was then thrown out of circuit, the next voltage being determined and applied in the same manner, and so on through all of the voltages. On changing over from ballast to test lamp a small adjustment of voltage (not exceeding 0.2 per cent.) was necessary since the resistances of test and ballast lamps were not quite equal.

Previous measurements had been made as follows:

The lamps while rotating were kept continuously in circuit and the voltages given applied in regular order ascending and decending by adjusting resistance, thus causing the filament to burn at all temperatures included in the voltage range.

Results on one lamp are given in Table VII. The differences on the other lamps were of about the same magnitude.

TABLE VII.—CURRENT BY UP AND DOWN METHOD.

Volts	Ampere Up	Ampere Down	Mean
72	0.26200	0.26248	0.26224
80	0.27905	0.27940	0.27922
88	0.29527	0.29556	0.29542
96	0.31083	0.31103	0.31093
104	0.32574	0.32599	0.32586
112	0.34022	0.34035	0.34028
120	0.35413	0.35430	0.35422
128	0.36781	0.36782	0.36782
136	0.38083	0.38087	0.38085
144	0.39365	0.39368	0.39366

Because of differences between up and down readings at voltages below 112, the method of direct voltage application described above was employed at each voltage from 72 to 112 inclusive, the order of application and observed ampere values being as shown in Table VIII.

TABLE VIII.—CURRENT, DIRECT VOLTAGE APPLICATION METHOD.

Volts	Ampere	Mean ampere	Mean amp. from up and down method
72	0.26231	0.26229	0.26224
112	0.34025	0.34023	0.34028
80	0.27924	0.27920	0.27922
96	0.31092	0.31090	0.31093
88	0.29538	0.29536	0.29542
104	0.32582	0.32582	0.32586
112	0.34021		
72	0.26227		
104	0.32581		
96	0.31087		
80	0.27915		
88	0.29533		

The up and down method had shown values which were very close to those obtained from equation 4 between 112 and 144 volts, but at the lower voltages the residuals were of greater magnitude. The probability of these residuals being greater is indicated by increasing deviations from the mean as the lower voltages are reached. That the method of direct voltage application obviates this difficulty is shown in the following table, in which observed values of current from 72 to 112 volts are those found by this method.

TABLE IX.—COMPARISON OF COMPUTED AND OBSERVED VALUES OF CURRENT.

Mean of Three 40-Watt Lamps.

Volts	Ampere Computed	Ampere Observed	Deviation of observed from computed values
72	0.26183	0.26176	0.00007
80	0.27874	0.27865	0.00009
88	0.29481	0.29478	0.00003
96	0.31028	0.31027	0.00001
104	0.32522	0.32516	0.00006
112	0.33956	0.33956	0.00000
120	0.35346	0.35346	0.00000
128	0.36696	0.36696	0.00000
136	0.38007	0.38001	0.00006
144	0.39281	0.39280	0.00001
		Average	0.011%

2. *Application to "Getter" Lamps of Various Sizes and Manufacture.*—The following are "getter" lamps of recent manufacture seasoned at the Bureau.

TABLE X.

Size of lamp	Volts	Candle-power Computed	Candle-power Observed		Dev. in %
25-watt	88	8.49	8.50		0.12
	99	13.18	13.14		0.30
	110	19.37	19.37		0.00
	121	27.22	27.11		0.41
	W. p. c. 1.97 to 1.02			Mean	0.21%
40-watt	88	15.34	15.29		0.33
	99	23.74	23.78		0.17
	110	34.73	34.78		0.14
	121	48.63	48.68		0.10
	W. p. c. 1.80 to 0.94			Mean	0.14%
60-watt	88	22.44	22.43		0.05
	99	34.71	34.75		0.12
	110	50.78	50.82		0.08
	121	71.09	71.12		0.04
	W. p. c. 1.78 to 0.93			Mean	0.07%
100-watt	88	40.34	40.41		0.17
	99	62.21	62.20		0.02
	110	90.74	90.49		0.28
	121	126.7	126.8		0.08
	W. p. c. 1.66 to 0.88			Mean	0.14%

XI. USE OF CHARACTERISTIC EQUATIONS IN STANDARDIZING LAMPS.

1. *Lamps Standardized for Voltage at a Specified Candle-power.*—The following illustrates the application of the characteristic equations in standardizing work. The lamps considered were of recent manufacture and were to be standardized as follows:

Lamp. No.	Size	Required
Nos. 1 and 2	25-watt	Volts for 20 candles
Nos. 3 and 4	40-watt	Volts for 34 candles
Nos. 5, 6 and 7	60-watt	Volts for 52 candles

The lamps were photometered at five voltages corresponding to the following and against the standards mentioned: 1. In color match with 4 w. p. c. carbon standards; 2. In color match with 1.5 w. p. c. tungsten standards; 3. At two voltages corresponding as nearly as possible to, but on either side of, the required candle-powers, these observations involving color difference with tungsten standards; 4. In color match with tungsten standards whose candle-power values are known through a wide range in voltage, this group including three of the lamps first investigated and three lamps calibrated as working standards in terms of the original group.

The observed values of candle-power and the values of w. p. c. obtained from observed values of voltage and amperes are given in Table XI. Values obtained by the third method (see above) are not given in this table, as they involve measurements at two voltages, one above and the other below the candle-power values required.

TABLE XI.—Observed Values.

Lamp	First method			Second method			Fourth method		
No.	Volts	Cp.	W.p.c.	Volts	Cp.	W.p.c.	Volts	Cp.	W.p.c.
1	68.7	3.83	3.006	97.6	12.66	1.508	106.8	20.04	1.158
2	69.6	3.87	3.001	96.0	13.15	1.474	107.9	20.00	1.166
3	68.5	6.31	3.036	95.0	21.98	1.467	107.2	34.15	1.144
4	68.2	6.17	3.077	95.0	21.87	1.473	107.3	34.11	1.144
5	68.5	8.94	3.069	95.0	31.10	1.485	109.6	52.20	1.109
6	70.8	9.19	3.071	97.3	31.12	1.506	112.1	52.04	1.128
7	70.8	9.20	3.060	97.6	31.14	1.508	112.3	51.66	1.136

From these observed values for each lamp the voltage for the

candle-power required was computed, the value obtained for each being as given in the following table:

TABLE XII.—VOLTAGES FOR REQUIRED CANDLE-POWER.

Lamp No.	First method	Second method	Third method	Fourth method	Means
1	106.7	106.65	106.75	106.8	106.7
2	107.7	107.75	107.9	107.9	107.8
3	107.2	107.1	107.2	107.1	107.2
4	107.3	107.3	107.25	107.2	107.3
5	109.5	109.5	109.55	109.5	109.5
6	112.2	112.1	112.15	112.1	112.1
7	112.3	112.4	112.3	112.5	112.4
Means	109.0	109.0	109.0	109.0	109.0

In Table XIII the observed candle-power values at the voltages corresponding to color match with tungsten standards (see Table XI) are compared with the values obtained by computation from observed values at carbon color.

TABLE XIII.

Lamp No.	Computed cp.	Observed cp.	Dev. Per cent.
1	12.63	12.66	0.24
2	13.17	13.15	0.15
3	21.92	21.98	0.27
4	21.87	21.87	0.00
5	31.14	31.10	0.13
6	30.95	31.12	0.55
7	31.32	31.14	0.57
Means	23.29	23.29	0.27%

It should be noted that the above lamps were not adjusted to a mean of 23.29 c. p., but that the mean of the seven lamps *is actually identical.*

2. *Lamps Standardized at Given Voltage by Computation from Values Observed at Color Match With 4-w. p. c. Carbon Standards.*—Table XIV illustrates what may be accomplished by computation of candle-power from values determined at a single voltage. These lamps are 60-watt Osram standards (sintered filament) which were measured about two years ago by the Bureau directly in terms of the 4 w. p. c. primary carbon standards with which they were matched in color by the use of calibrated blue glass screens. These lamps had been previously measured at the National Physical Laboratory, England, in

terms of a corresponding group of carbon standards. In both laboratories all measurements were made with the lamps operating at 102.0 volts corresponding to about 1.5 w. p. c.

In order to determine how well the equations apply, the lamps were measured a short time ago, not at 1.5 w. p. c., but at color match with 4 w. p. c. carbon standards. At this color their efficiency was about 3.1 w. p. c., the corresponding voltages of the various lamps being approximately 71. From the values thus obtained those given in column (a) of the table were computed. The values in columns (b) and (c) are, respectively, the certified values of the laboratory indicated.

TABLE XIV.

	Candle-power			Deviations in per cent.	
Lamp No.	(a) Computed values	(b) B. S. obs. values	(c) N. P. L. obs. values	(b-a)	(c-a)
57-i	31.9	32.0	31.95	+0.31	+0.16
-j	27.7	27.85	27.7	+0.54	±0.00
-k	32.85	32.85	32.85	±0.00	±0.00
-l	32.45	32.35	32.35	—0.31	—0.31
-m	32.25	32.05	32.1	—0.62	—0.47
-n	31.75	31.55	31.5	—0.63	—0.79
Means	31.48	31.44	31.41	0.38	0.29

Evidently measurements at color match with either carbon or tungsten standards will suffice to determine the values for candle-power; further, values of candle-power or voltage at any intermediate point can be computed from the color match observations with no sacrifice in precision, the great advantage being in the elimination of personal errors due to color difference.

However, the following points should receive careful attention in this connection. 1. In adjusting the voltage of tungsten lamps for color match with carbon standards great care should be exercised because if a color match is not really obtained two observers of like color perception may introduce errors which do not counterbalance even though their observations may appear consistent and conclusive: 2. candle-power values of the smaller sizes of lamps being low, small differences in distance from the test lamps for photometric balance result in considerable differences in observed candle-power values, so that deter-

minations at this point should be made with the highest degree of accuracy attainable and all confusing features should be eliminated.

XII. CONCLUSION.

The results found in this investigation show that for 100-130 volt tungsten lamps of the ordinary sizes an equation of the

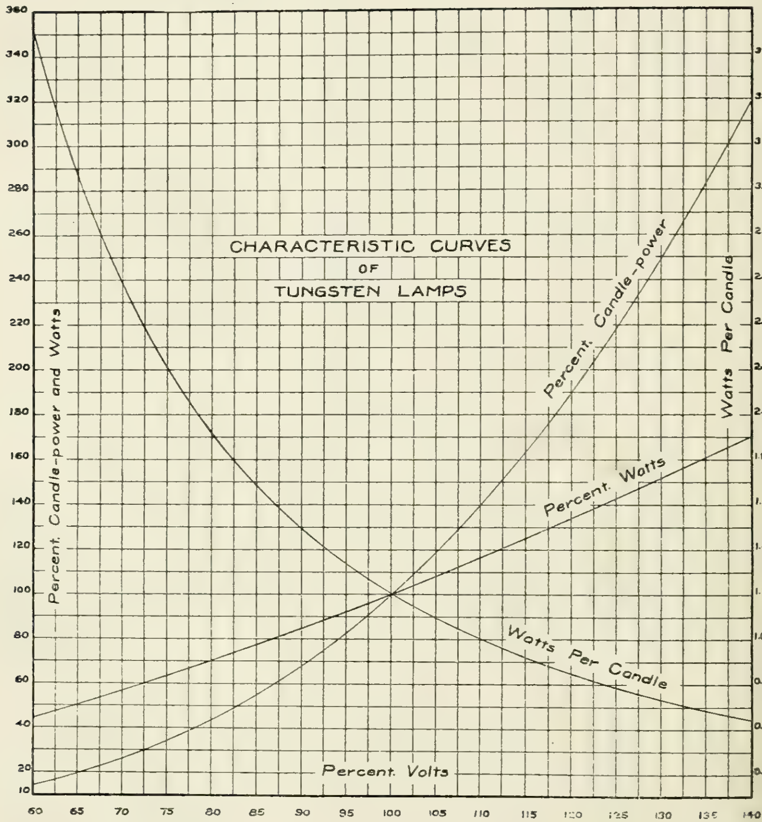

Fig. 1.—Characteristic curves of 100-130-volt vacuum tungsten filament lamps of sizes 25 to 100 watts for the range included between 0.7 and 3 7 w.p.c. 100 per cent. values being at 1.20 w.p.c.

form $y = Ax^2 + Bx + C$ expresses the voltage-candle-power and the voltage-w. p. c. relations to within 0.3 per cent. and the voltage-wattage relation to within 0.05 per cent. of the observed values over the whole range investigated; *viz.,* from 0.7 w. p. c. to

3.3 w. p. c., the latter limit extending somewhat beyond the w. p. c. corresponding to color match with 4-w. p. c. carbon lamps.

It is, therefore, possible, after carefully standardizing a tungsten lamp at color match with the carbon primary standards which maintain the international candle unit, to calculate with a high degree of precision its candle-power and voltage at any desired efficiency (or color) within the range mentioned. In this manner groups of standards at different efficiencies may be established in terms of the primary standards without a single measurement made with a color difference. Likewise color screens, to be used as auxiliaries, may be calibrated with a degree of precision equal to that of ordinary photometric measurements at color match.

Further, any standardized tungsten lamp of the size and voltage investigated, together with the set of tables herein given, is virtually a standard at any efficiency within the range above specified, because its candle-power and current can be completely determined from a knowledge of the corresponding observed voltage.

The investigation has been extended to include gas-filled tungsten lamps and the results, though yet incomplete, indicate that the same equations, with little if any change in the constants, apply to these lamps also.

The authors acknowledge the assistance of the men of laboratory especially of Mr. D. H. Tuck who had immediate supervision of the photometric measurements and to Mr. H. B. Sinelnick who drew the curves and checked most of the computations.

APPENDIX.

EXPLANATION OF USE OF TABLES.

The first step in the solution of every problem involving characteristic equations is to determine from the observed values of voltage candle-power and w. p. c., the corresponding values at normal efficiency, which for these tables was chosen at 1.20 w. p. c.

This is done by reference to Table XV in which *observed* w. p. c. in steps of 0.1 and intermediate steps of 0.01 are given at the top and left margin respectively. In the body of the table under "volts" and "cp." respectively are given the corresponding *percentage* factors by which the *observed* voltage and *observed*

candle-power respectively are to be multiplied to reduce them to normal values. Normal watts are found by multiplying normal candle-power by 1.20.

For example, if the observed values are: voltage 110, cp. 25, w. p. c. 1.35, the corresponding normal values are found as follows: Corresponding to 1.35 w. p. c. find 106.0 under volts and 123.3 under cp. Then $110 \times 1.060 = 116.6$ = normal voltage, and $25 \times 1.233 = 30.82$ = normal candle power. $30.82 \times 1.20 = 36.98$ = normal wattage.

With these values known we are in a position to read from one of the other three tables (*viz.*, XVI–XVIII) values corresponding to any desired percentage value of any one of the variables given.

The simplest problem is when values corresponding to a given voltage are required, because all three tables are arranged for voltage considered as the independent variable and the other variables are given in the body of the table.

For example, assuming the normal values just found, suppose values for candle-power, watts and w. p. c. corresponding to 125 volts are required. The voltage ratio expressed in percentage $= 125 \div 1.166 = 107.2$ per cent. Corresponding to 107.2 per cent. volts in Tables XVI, XVII and XVIII, find 128.1 per cent. cp., 111.63 per cent. watts and 1.045 actual w. p. c. respectively. The numerical values corresponding to these percentage values are found by multiplying each by the corresponding normal value as follows:

$1.281 \times 30.82 = 39.48$ cp. and $1.1163 \times 36.98 = 41.28$ watts.

Hence the corresponding values of all the variables are voltage 125.0, cp. 39.48, watts 41.28 and w. p. c. 1.045.

As a second problem suppose that the values of voltage, watts and w. p. c. corresponding to 20 candle-power are required, the same normal values being assumed. This candle-power value is $20 \div 30.82 = 64.9$ per cent. of normal. From 64.9 per cent. cp. in the *body* of Table XVI find the corresponding voltage per cent. at the top and margin; that is, $88.0 + (2.14 \div 2.67) = 88.8$ per cent. volts. With this value known find 82.846 per cent. watts in Table XVII and 1.532 actual w. p. c. in Table XVIII. Multiplying per cent. values by corresponding normal values, we have,

$0.888 \times 116.6 = 103.5$ volts and $0.82846 \times 36.98 = 30.64$ watts. The variables are therefore cp. 20.0, voltage 103.5, watts 30.64 and w. p. c. 1.532.

In the same manner values for all the variables corresponding to a given value of watts or w. p. c. may be found also.

REDUCTION OF VALUES TO A W. P. C. BASIS OTHER THAN 1.20.

If some other w. p. c. than 1.20 be chosen as normal, tables of values can be readily determined from these tables as follows. Suppose for example that 1.25 w. p. c. is chosen. Corresponding to 1.25 in Table XVIII find 98 per cent. volts. Corresponding to 98 per cent. volts in Tables XVI and XVII find 92.98 per cent. cp. and 96.852 per cent. watts. Therefore the values in the present tables corresponding to normal in the new table are as follows:

98.0 per cent. volts.
92.98 per cent. cp.
96.852 per cent. watts.
1.25 actual w. p. c.

For example suppose values at 105.0 per cent. volts on the new basis are required. Voltage ratio is then $98.0 \times 1.050 = 102.9$ per cent. Corresponding to 102.9 per cent. volts in Tables XVI, XVII and XVIII find 110.8 per cent. cp., 104.63 per cent. watts and 1.133 actual w. p. c.

Hence corresponding to 105.0 per cent. volts we have for the new table:

$102.9 \div 0.980 = 105.0$ per cent. volts.
$110.8 \div 0.9298 = 119.2$ per cent. cp.
$104.63 \div 0.96852 = 108.03$ per cent. watts
and $1.133 =$ actual w. p. c.

In the same manner values corresponding to any other percentage value of voltage may be found, and a complete set of tables on the new basis may be constructed.

TABLE XV.

Table of percentage multiplying factors for reducing observed values of voltage and observed values of candle-power at known w.p.c. to values they would have at 1.20 w.p.c. Voltage factors are indicated by 'Volts'; candle-power factors by 'Cp.'

Example: Given as observed values, voltage 112.0, candle-power 16.0, w.p.c. 1.450, to find voltage and candle-power at 1.20 w.p.c.

Solution: Corresponding to 1.450 w.p.c. find 109.7, the voltage percentage multiplier, and 139.9, the candle-power percentage multiplier. The values corresponding to 1.20 w.p.c. are, therefore, 112.0 × 1.097 = 122.86 volts, and 16.0 × 1.399 = 22.38 candles.

Obs. w.p.c.	0.70				0.80				0.90				1.00			
	Volts	Dif.	Cp.	Dif.	Volts	Dif.	Cp.	Dif.	Volts	Dif.	Cp.	Dif.	Volts	Dif.	Cp.	Dif.
0.00	75.26		37.23		81.01		47.79		86.29		59.40		91.17		72.00	
0.01	75.86	0.60	38.24	1.01	81.56	0.55	48.90	1.11	86.79	0.50	60.61	1.21	91.64	0.47	73.31	1.31
0.02	76.45	0.59	39.26	1.02	82.10	0.54	50.03	1.13	87.29	0.50	61.84	1.23	92.11	0.47	74.63	1.32
0.03	77.04	0.59	40.29	1.03	82.64	0.54	51.16	1.13	87.79	0.50	63.07	1.23	92.57	0.46	75.96	1.33
0.04	77.62	0.58	41.33	1.04	83.17	0.53	52.31	1.15	88.28	0.49	64.32	1.25	93.03	0.46	77.31	1.35
0.05	78.20	0.58	42.38	1.05	83.70	0.53	53.47	1.16	88.77	0.49	65.57	1.25	93.49	0.46	78.66	1.35
0.06	78.77	0.57	43.44	1.06	84.23	0.53	54.64	1.17	89.26	0.49	66.84	1.27	93.94	0.45	80.02	1.36
0.07	79.34	0.57	44.51	1.07	84.75	0.52	55.81	1.17	89.74	0.48	68.11	1.27	94.39	0.45	81.38	1.36
0.08	79.90	0.56	45.60	1.09	85.27	0.52	57.00	1.19	90.22	0.48	69.40	1.29	94.84	0.45	82.76	1.38
0.09	80.46	0.56	46.69	1.09	85.78	0.51	58.19	1.19	90.70	0.48	70.69	1.29	95.29	0.45	84.14	1.38
0.10	81.01	0.55	47.79	1.10	86.29	0.51	59.40	1.21	91.17	0.47	72.00	1.31	95.73	0.44	85.54	1.40

TABLE XV.—(*Continued.*)

Obs. w.p.c.	1.10				1.20				1.30				1.40			
	Volts	Dif.	Cp.	Dif.	Volts	Dif.	Cp.	Dif.	Volts	Dif.	Cp.	Dif.	Volts	Dif.	Cp.	Dif.
0.00	95.73		85.54		100.0		100.0		104.0		115.3		107.8		131.5	
0.01	96.17	0.44	86.95	1.41	100.4	0.4	101.5	1.5	104.4	0.4	116.9	1.6	108.2	0.4	133.1	1.6
0.02	96.60	0.43	88.36	1.41	100.8	0.4	103.0	1.5	104.8	0.4	118.5	1.6	108.6	0.4	134.8	1.7
0.03	97.04	0.44	89.78	1.42	101.2	0.4	104.5	1.5	105.2	0.4	120.1	1.6	109.0	0.4	136.5	1.7
0.04	97.47	0.43	91.22	1.44	101.6	0.4	106.0	1.5	105.6	0.4	121.7	1.6	109.3	0.3	138.2	1.7
0.05	97.90	0.43	92.66	1.44	102.0	0.4	107.6	1.6	106.0	0.4	123.3	1.6	109.7	0.4	139.9	1.7
0.06	98.32	0.42	94.11	1.45	102.4	0.4	109.1	1.5	106.4	0.4	124.9	1.6	110.0	0.3	141.6	1.7
c.07	98.75	0.43	95.57	1.46	102.8	0.4	110.6	1.5	106.8	0.4	126.5	1.6	110.4	0.4	143.3	1.7
0.08	99.17	0.42	97.04	1.47	103.2	0.4	112.2	1.6	107.1	0.3	128.2	1.7	110.8	0.4	145.0	1.7
0.09	99.59	0.42	98.51	1.47	103.6	0.4	113.8	1.6	107.5	0.4	129.8	1.6	111.1	0.3	146.8	1.8
0.10	100.00	0.41	100.00	1.49	104.0	0.4	115.3	1.5	107.8	0.3	131.5	1.7	111.5	0.4	148.5	1.7

TABLE XV.—(*Continued.*)

Obs. w.p.c.	1.50				1.60				1.70				1.80			
	Volts	Dif.	Cp.	Dif.	Volts	Dif.	Cp.	Dif.	Volts	Dif.	Cp.	Dif.	Volts	Dif.	Cp.	Dif.
0.00	111.5		148.5		115.0		166.3		118.3		184.8		121.4		204.1	
		0.3		1.7		0.3		1.8		0.3		1.9		0.4		2.0
0.01	111.8		150.2		115.3		168.1		118.6		186.7		121.8		206.1	
		0.4		1.8		0.3		1.8		0.3		1.9		0.3		1.9
0.02	112.2		152.0		115.6		169.9		118.9		188.6		122.1		208.0	
		0.3		1.7		0.4		1.9		0.3		1.9		0.3		2.0
0.03	112.5		153.7		116.0		171.8		119.2		190.5		122.4		210.0	
		0.4		1.8		0.3		1.8		0.4		1.9		0.3		2.0
0.04	112.9		155.5		116.3		173.6		119.6		192.4		122.7		212.0	
		0.3		1.8		0.3		1.8		0.3		2.0		0.3		2.0
0.05	113.2		157.3		116.6		175.4		119.9		194.4		123.0		214.0	
		0.4		1.8		0.4		1.9		0.3		1.9		0.3		2.0
0.06	113.6		159.1		117.0		177.3		120.2		196.3		123.3		216.0	
		0.3		1.8		0.3		1.9		0.3		1.9		0.3		2.0
0.07	113.9		160.9		117.3		179.2		120.5		198.2		123.6		218.0	
		0.4		1.8		0.3		1.8		0.3		2.0		0.3		2.0
0.08	114.3		162.7		117.6		181.0		120.8		200.2		123.9		220.0	
		0.3		1.8		0.3		1.9		0.3		2.0		0.3		2.1
0.09	114.6		164.5		117.9		182.9		121.1		202.2		124.2		222.1	
		0.4		1.8		0.4		1.9		0.3		1.9		0.3		2.0
0.10	115.0		166.3		118.3		184.8		121.4		204.1		124.5		224.1	

TABLE XV.—(*Continued.*)

Obs. w.p.c.	1.90				3.00				3.10				3.20			
	Volts	Dif.	Cp.	Dif.	Volts	Dif.	Cp.	Dif.	Volts	Dif.	Cp.	Dif.	Volts	Dif.	Cp.	Dif.
0.00	124.5		224.1		152.3		487.9		154.4		515.4		156.5		543.5	
		0.3		2.1		0.3		2.7		0.2		2.7		0.2		2.8
0.01	124.8		226.2		152.6		490.6		154.6		518.1		156.7		546.3	
		0.3		2.0		0.2		2.7		0.2		2.8		0.2		2.9
0.02	125.1		228.2		152.8		493.3		154.8		520.9		156.9		549.2	
		0.3		2.1		0.2		2.7		0.2		2.8		0.2		2.8
0.03	125.4		230.3		153.0		496.0		155.0		523.7		157.1		552.0	
		0.3		2.0		0.2		2.8		0.3		2.8		0.2		2.9
0.04	125.7		232.3		153.2		498.8		155.3		526.5		157.3		554.9	
		0.3		2.1		0.2		2.7		0.2		2.8		0.3		2.9
0.05	126.0		234.4		153.4		501.5		155.5		529.3		157.6		557.8	
		0.3		2.1		0.2		2.8		0.2		2.9		0.2		2.9
0.06	126.3		236.5		153.6		504.3		155.7		532.2		157.8		560.7	
		0.3		2.1		0.2		2.7		0.2		2.8		0.2		2.8
0.07	126.6		238.6		153.8		507.0		155.9		535.0		158.0		563.5	
		0.3		2.1		0.2		2.8		0.2		2.9		0.2		2.9
0.08	126.9		240.7		154.0		509.8		156.1		537.9		158.2		566.4	
		0.3		2.1		0.2		2.8		0.2		2.8		0.2		2.9
0.09	127.2		242.8		154.2		512.6		156.3		540.7		158.4		569.3	
		0.2		2.1		0.2		2.8		0.2		2.8		0.2		2.9
0.10	127.4		244.9		154.4		515.4		156.5		543.5		158.6		572.2	

TABLE XVI.

Table for determining values of candle-power corresponding to observed values of voltage, when the values of both candle-power and voltage at 1.20 w.p.c. are known. All values in this table are expressed in per cent.

Example: Given voltage 125.0, and candle-power 34.0, both at 1.20 w.p.c. find candle-power at 100.0 volts.

Solution: 100.0 volts = 80 per cent. of 125.0 volts. Corresponding to 80 per cent. volts find in the table 43.95 per cent. candle-power. Therefore candle-power at 125.0 volts = 43.95 per cent. of 34.0 = 14.94 candles.

Obs. volts	60		70		80		90		100		110		120		130	
	Cp.	Dif.	Cp.	Dif.	Cp.	Dif.	Cp.	Dif.	Cp.	Dif.	Cp.	Dif.	Cp.	Dif.	Cp.	Dif.
0	14.34	0.98	26.35	1.49	43.95	2.11	68.18	2.83	100.0	3.6	140.3	4.5	189.9	5.5	249.5	6.5
1	15.32	1.03	27.84	1.55	46.06	2.18	71.01	2.90	103.6	3.8	144.8	4.6	195.4	5.6	256.0	6.6
2	16.35	1.07	29.39	1.61	48.24	2.24	73.91	2.98	107.4	3.8	149.4	4.8	201.0	5.7	262.6	6.8
3	17.42	1.12	31.00	1.66	50.48	2.31	76.89	3.05	111.2	3.9	154.2	4.8	206.7	5.8	269.4	
4	18.54	1.18	32.66	1.73	52.79	2.39	79.94	3.14	115.1	3.9	159.0	4.9	212.5	5.9		
5	19.72	1.22	34.39	1.79	55.18	2.45	83.08	3.22	119.0	4.1	163.9	5.0	218.4	6.0		
6	20.94	1.28	36.18	1.85	57.63	2.53	86.30	3.30	123.1	4.2	168.9	5.1	224.4	6.1		
7	22.22	1.33	38.03	1.91	60.16	2.60	89.60	3.38	127.3	4.2	174.0	5.2	230.5	6.2		
8	23.54	1.38	39.94	1.97	62.76	2.67	92.98	3.47	131.5	4.4	179.2	5.3	236.7	6.3		
9	24.92	1.43	41.91	2.04	65.43	2.75	96.45	3.55	135.9	4.4	184.5	5.4	243.0	6.5		
10	26.35		43.95		68.18		100.00		140.3		189.9		249.5			

TABLE XVII.

Table for determining values of watts corresponding to observed values of voltage when the values of both watts and voltage at 1.20 w.p.c. are known. All values in this table are expressed in per cent.

Example: Given watts 98.0 and voltage 110.0, both at 1.20 w.p.c., find watts at 90.2 volts.

Solution: 90.2 volts = 82 per cent. of 110.0 volts. Corresponding to 82 per cent. find in the table 73.007 per cent. watts. Therefore, watts at 90.2 volts = 73.007 per cent. of 98.0 = 71.55 watts.

Obs. volts	60		70		80		90		100		110		120		130	
	Watts	Dif.	Watts	Dif.	Watts	Dif.	Watts	Dif.	Watts	Dif.	Watts	Dif.	Watts	Dif.	Watts	Dif.
0	44.406	1.187	56.772	1.295	70.200	1.399	84.628	1.495	100.00	1.59	116.27	1.68	133.40	1.76	151.35	1.84
1	45.593	1.198	58.067	1.307	71.599	1.408	86.123	1.505	101.59	1.60	117.95	1.68	135.16	1.77	153.19	1.85
2	46.791	1.209	59.374	1.317	73.007	1.419	87.628	1.514	103.19	1.60	119.63	1.69	136.93	1.77	155.04	1.85
3	48.000	1.220	60.691	1.328	74.426	1.428	89.142	1.524	104.79	1.61	121.32	1.70	138.70	1.79	156.89	
4	49.220	1.231	62.019	1.338	75.854	1.438	90.666	1.533	106.40	1.63	123.02	1.71	140.49	1.79		
5	50.451	1.243	63.357	1.348	77.292	1.448	92.199	1.542	108.03	1.63	124.73	1.72	142.28	1.80		
6	51.694	1.253	64.705	1.359	78.740	1.458	93.741	1.551	109.66	1.64	126.45	1.72	144.08	1.80		
7	52.947	1.264	66.064	1.368	80.198	1.467	95.292	1.560	111.30	1.65	128.17	1.74	145.88	1.82		
8	54.211	1.275	67.432	1.379	81.665	1.477	96.852	1.570	112.95	1.65	129.91	1.74	147.70	1.82		
9	55.486	1.286	68.811	1.389	83.142	1.486	98.422	1.578	114.60	1.67	131.65	1.75	149.52	1.83		
10	56.772		70.200		84.628		100.000		116.27		133.40		151.35			

TABLE XVIII.

Table for determining watts per candle corresponding to observed voltage when the latter is expressed in per cent. of the voltage at 1.20 w.p.c.

Example: Given voltage at 1.20 w.p.c. 115.0, find watts per candle corresponding to 96.6 volts.

Solution: 96.6 volts = 84.0 per cent. of 115.0 volts. Corresponding to 84 per cent. volts, find in the table 1.724, the w.p.c. required.

Obs. volts	60		70		80		90		100		110		120		130	
	W.p.c.	Dif.	W.p.c.	Dif.	W.p.c.	Dif.	W.p.c.	Dif.	W.p.c.	Dif.	W.p.c.	Dif.	W.p.c.	Dif.	W.p.c.	Dif.
0	3.716	0.145	2.585	0.083	1.916	0.051	1.490	0.034	1.200	0.024	0.9945	0.0172	0.8431	0.0130	0.7280	0.0098
1	3.571	0.136	2.502	0.078	1.865	0.049	1.456	0.033	1.176	0.023	0.9773	0.0167	0.8301	0.0126	0.7182	0.0098
2	3.435	0.129	2.424	0.075	1.816	0.047	1.423	0.032	1.153	0.022	0.9606	0.0163	0.8175	0.0122	0.7084	0.0095
3	3.306	0.121	2.349	0.071	1.769	0.045	1.391	0.030	1.131	0.021	0.9443	0.0157	0.8053	0.0119	0.6989	
4	3.185	0.115	2.278	0.067	1.724	0.043	1.361	0.029	1.110	0.021	0.9286	0.0153	0.7934	0.0116		
5	3.070	0.108	2.211	0.065	1.681	0.041	1.332	0.028	1.089	0.020	0.9133	0.0149	0.7818	0.0113		
6	2.962	0.102	2.146	0.061	1.640	0.040	1.304	0.028	1.069	0.020	0.8984	0.0144	0.7705	0.0110		
7	2.860	0.097	2.085	0.059	1.600	0.038	1.276	0.026	1.049	0.018	0.8840	0.0140	0.7595	0.0108		
8	2.763	0.091	2.026	0.056	1.562	0.037	1.250	0.026	1.031	0.019	0.8700	0.0136	0.7487	0.0105		
9	2.672	0.087	1.970	0.054	1.525	0.035	1.224	0.024	1.012	0.0175	0.8564	0.0133	0.7382	0.0102		
10	2.585		1.916		1.490		1.200		0.9945		0.8431		0.7280			

DISCUSSION.

Dr. C. H. Sharp: The work Dr. Middlekauff has presented to us seems to me to be of the very greatest practical and theoretical value, a value which is not limited only to the making of standards, but which extends also to the realm of actual testing of lamps. The authority which is given to these interpolation formulas for tungsten lamps, as a result of this investigation, is very great. I think perhaps we might add one word of caution, that is, lamp makers may possibly change some of the more intimate features of their manufacture without advising the general public, and these changes may have an influence on the equations and constants presented by Dr. Middlekauff as a result of his experiments on lamps heretofore made.

Mr. G. M. J. Mackay: I am sure that all of us who are working on lamp problems are very much indebted to the painstaking work Dr. Middlekauff has carried on, and his equations and tables will be extremely useful, but there is one thing to which I should like to call attention. The method of standardization depends upon the intensity of different colors as measured by the Lummer-Brodhun photometer. I should like to ask how this checks with similar readings made with the flicker photometer?

Mr. T. H. Amrine: I am very much interested in this paper for the reason that for the past year and a half I have been in close touch with the practical use of the method utilizing characteristic curves for eliminating the bugbear of heterochromatic photometry from routine measurements upon tungsten lamps. It has been found desirable to reduce the rating of all vacuum type tungsten lamps to measurements at a single efficiency, 1.23 watts per candle. Thus, although the lamps have to be rated at efficiencies ranging from 1.5 to 0.7 watt per candle in the factory and laboratory, there is practically no photometry at a color difference. If it is desired to rate a lamp at 0.95 watt per candle, for instance, it is not photometered at this efficiency but at 1.23 watts per candle, and by means of the characteristic curves the voltage at 0.95 watt per candle is determined. It has been found that this method leads to very much more satisfactory results than the old method of photometering the lamps directly at the efficiencies at which they are to be rated.

I am very glad that the Bureau of Standards has investigated this method and shown its possibilities and it is gratifying to me to find that the curves which have been determined in the work in which I have been engaged agree very closely with the curves obtained by Dr. Middlekauff and Mr. Skogland even in the extreme points in the range.

Mr. F. E. Cady: It seems to me that the work given in this paper very aptly bears out my previous statement regarding the desirability of referring the color difference difficulty to a standard referee. It will be noted that the method given here does not eliminate the color difference in photometry entirely, but merely localizes it in one place. As stated on the seventh page of the paper, in determining the candle-power values at the different voltages, it was necessary to have a color difference. If, then, we can accept the work of the Bureau as a final point of reference, it would seem that the difference could be obviated by obtaining from the Bureau lamps or screens properly calibrated for transmission and covering the different color values required. I should like to ask Dr. Middlekauff whether, in going from one voltage to another, they found any material difficulties on the part of the observers in getting consistent results due to the constantly increasing difference in color? As I understand the statement on the seventh page the lamps were started with a color match at 4 watts per candle-power and measurements were made at succeeding voltages until a voltage was reached, the lamp matched 2 watts per candle-power. From 2 to 1.25 watts per candle-power tungsten lamps were used, in which case the color differences would be reversed.

Dr. H. E. Ives: I would like to contribute to this general discussion a little analogy by way of pointing out what has already been pointed out by Dr. Middlekauff, that all these results are dependent on the photometric method employed. I think the only danger that may lie in this paper is that the results are of such wonderful precision that those people who mistake precision for accuracy may draw wrong conclusions. The analogy I want to suggest is this: Dr. Mees, Dr. Middlekauff, Dr. Kingsbury and myself have presented for your inspection watches of our manufacture. Dr. Mees claims that his watch will keep

time within five seconds per day. Dr. Middlekauff comes along and says that his watch will keep time within one-fifth of a second per day. The great problem we have ahead of us is to set all these watches, to establish a standard time. Dr. Mees brings his here without setting it; Dr. Middlekauff has his set to Washington time; ours is Philadelphia time. Now, it is the function of the Bureau of Standards to establish standard time, after the Bureau or other laboratories have found what shall be taken as standard time, but these various contributions to-day I would like to classify as watches which will run accurately after setting. Experience will tell which one of these will make the dollar famous and which will be used to actuate wireless time signals.

Now there is an important difference between the papers of Dr. Mees[1] and Dr. Middlekauff on the one hand and that[2] of Mr. Kingsbury and myself on the other. It is this: Dr. Mees makes no attempt to set his watch to any definite time; Dr. Middlekauff sets his to a time which merely happens to be handy, but our contribution is more than a well regulated watch, it is a watch set to a time which has been determined by a process of careful investigation. To abandon the metaphor, our results are in conformity with a scientifically worked out scheme of colored light photometry.

Dr. P. G. Nutting: While we are having this symposium on two-color photometry, I should like to suggest two other methods of overcoming color difference. The problem is a difficult and important one, and it seems worth while to try out every possible method of obtaining a color match by definitely measurable means.

Three very good methods have been proposed this morning: the use of the fixed color filters that we have worked out in Rochester, the use of colored solutions (Ives) and extrapolation each way from a color match along previously determined curves (Middlekauff and Skogland).

Instead of interposing color filters between the source and photometer screen, we might stain one side of the photometer

[1] C. E. K. Mees, Light Filters for Use in Photometry, Trans. I. E. S., Vol. IX, No. 8.

[2] H. E. Ives and E. F. Kingsbury, Experiments with Colored Absorbing Screens for Use in Heterochromatic Photometry, Trans. I. E. S., Vol. IX, No. 8.

screen itself. Such stains are readily applied and a set of prepared photometer screens would serve the same purpose as a set of prepared filters.

Another method of promise would be to throw a part of a spectrum on one side of the photometer screen by attaching a small simple spectroscope to the bench at a slight angle. In this way any desired amount of light of any desired hue may be mixed with the light from either source, thus producing a color match. The small amount of pure hue added may be determined with the required precision since it is a small fraction of the whole light.

I think that Dr. Middlekauff has hit the nail on the head with his extrapolation method. This is the basis of all our null methods; if we cannot work to an absolute balance, we determine a little bit of the curve each way from a balance. In using a Wheatstone bridge for example, we assume that our galvanometer deflection is proportional to the slight departure from balance. This method appears to me to be thoroughly sound and particularly valuable in that it involves the application of precise mathematical reasoning.

Mr. E. L. Clark: I agree with Mr. Nutting that Messrs. Middlekauff and Skogland have hit the nail on the head. Although this is not a complete solution of the problem of heterochromatic photometry, is is a very important advance. It insures that any general agreement on the candle-power of a series of standard lamps of different colors, may be easily made use of in the various laboratories throughout the country through exceedingly convenient and accurate procedure. I believe that this method will largely supplant the use of colored screens over the range of color match which it affords. Regarding the possibility of variation and change in the lamps made by manufacturers introducing a possible source of error in the application of this method, I do not believe that such a possibility can militate much against its usefulness. The work of the authors of this paper has shown that a large number of lamps of considerable variety fit the equation deduced. This is sufficient to show that it is easily possible for lamp manufacturers to produce lamps fitting the equation. Lamps fitting this equation can

be selected and certified by our standardizing laboratories, and in this manner we can be assured of a source of reliable lamps for photometric use. So irregularities in manufacture need cause no alarm in this connection.

Mr. J. B. Taylor: I think it should be clearly stated that the tables apply to vacuum lamps.

Dr. G. W. Middlekauff: It should be emphasized that the method outlined in this paper is not in the least affected by the kind of photometer used in determining the characteristic equations. The color difference difficulties are encountered once for all and it is immaterial as to whether it is done by means of an equality of brightness or a flicker photometer. The only effect resulting from a possible difference in value obtained by the use of the flicker photometer would be a slight change in the constants of the equations.

All values given were based upon two groups of standards, one group being duplicates of the Bureau's primary carbon standards. Concerning the correct values of this group, therefore, certainly no question can be raised. The other group consisted of 1.5 w. p. c. tungsten lamps standardized in terms of a group of the same kind of lamps the values of which were determined by direct comparison with the primary carbon standards and independently checked by the National Physical Laboratory, England, in terms of a similar group of carbon standards. In the English laboratory the step from the carbon standards was made by the cascade method, while at the Bureau of Standards it was made by the use of two calibrated blue glass screens of practically the same transmission coefficient.

In order to obtain additional checks upon the values given in the paper, by different methods and by different groups of observers, several of the lamps used in this investigation and three glass screens of different density have been sent out on a circuit to a number of other photometric laboratories which have agreed to co-operate with the Bureau in an inter-laboratory intercomparison.

The transmission coefficient of one of these glasses is approximately equal to the coefficients of the two used in determining the values of the tungsten standards employed in the intercom-

parison with England. Each of the lamps submitted to the various laboratories is to be measured at several different voltages in terms of its value at a specified voltage, and the transmission of each glass is to be determined for the light of a 4 w. p. c. carbon lamp which was sent along with the glasses. As Dr. Ives' laboratory is one of the number co-operating in this intercomparison, we hope to obtain results which (to use Dr. Ives' metaphor) will show how nearly his watch and that of the Bureau of Standards as well as those of the other laboratories, including the National Physical Laboratory, are set to the same time. I regret that on account of unavoidable delays in some of the laboratories I am unable to give a report of this intercomparison at this time.

As no measurements were made with the flicker photometer, I am, therefore, unable, from experience, to answer Mr. Mackay's question as to how well readings made with the flicker photometer would agree with those made with the Lummer-Brodhun.

To answer Mr. Cady's question, I would say that the average deviations of the observers from their own mean as well as from the mean of all was practically the same throughout the range of color within which measurements were made. In other words, there was no regular increase in deviations with increase in color difference showing that no special difficulty was experienced by the observers in passing from one degree of color difference to another.

In conclusion, I wish to say that although the fundamental idea of eliminating color difference by the method outlined in this paper was developed by one of the authors more than three years ago, the results of measurements made at that time were very unsatisfactory. The variations in current and candle-power due to variable contact between the filament and anchor wires of tungsten lamps then on the market were much greater than the errors of photometric measurement. After the specially made lamps described in section VI were received, no further difficulty in this particular was experienced.

THE CHARACTERISTICS OF GAS-FILLED LAMPS.*

BY G. M. J. MACKAY.

Synopsis: After a short discussion of the properties of tungsten as a filament material for incandescent lamps, the general effect of the introduction of gases into the bulb is considered. The effect of increased temperatures of the filament upon the color of the emitted light is shown, in comparison with average daylight. The shape of the filament in its bearing on the characteristics of the lamp is discussed. Finally, the volt–ampere–candle-power characteristics of the filament are considered, as affected by the kind of gas and its pressure, and the size of wire used. The relationship between size of filament and life of gas-filled lamps, and the variation of efficiency necessary to maintain a uniform life for lamps of different current ratings, is discussed in detail.

In this discussion of the characteristics of gas-filled lamps the matter is not taken up with the view of providing accurate physical data but rather with the idea of considering the principles involved in the various modifications of the different types of lamps mentioned. The designing engineer and the photometrist will therefore not find detailed results governing the manufacture and operation of such lamps, but may obtain some guide as to the cause and magnitude of differences to be expected when variations are made in the factors involved.

Before proceeding further, however, it may be well to briefly consider the characteristics of tungsten as a filament material, which have placed it in the unrivalled position it now occupies.

The factors which are of chief importance in the selection of a substance to be used as an efficient light source from among those otherwise suitable, are (1) melting point, (2) volatility, and (3) selectivity of radiation.

The candle-power of an incandescent body increases very rapidly with the temperature, though the *rate* of increase decreases as the temperature rises. Thus tungsten at 2,000° K,**

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

** Degrees Kelvin = Centigrade degrees on the absolute scale = degrees C + 273.

approximately 4 watts per candle, is increasing in candle-power 13 times as rapidly as the temperature—1 per cent. increase in the temperature causing an increase of 13 per cent. in the candle-power. At 3,000° K, about 0.35 watt per candle, the rate of increase, though not quite so rapid, is still 8.6 times the rate of temperature increase. The total energy radiated, on the other hand, increases continually with very nearly the fifth power of the temperature. Until, then, the rate of increase of candle-power with temperature lessens to the rate at which total energy is being dissipated, the efficiency of the substance as a source of light increases as the temperature rises. Consequently, up to a certain point, the higher temperature which a metal will stand, the more efficient it becomes as an illuminant. The point at which the rate of increase of candle-power becomes no greater than the increase in total watts marks the point of maximum light efficiency. For a black body, or ideal radiator, this occurs at about 6,000° K, which is approximately the temperature of the sun. After this point is reached, the candle-power, or that fraction of total radiation to which the eye is sensitive, increases more slowly than the energy required to maintain the temperature, so that the efficiency for *visible* light is lessened. The light becomes bluer in color, the wave-length of maximum energy emission being shifted continually towards the shorter wave-lengths as the temperature is raised.

It is evident from the rapid increase of candle-power with temperature that only a slight difference in the refractory qualities of substances may mean a good deal in efficiency of light production. No material available can be operated at anything like the temperature of maximum efficiency, and most of the substances investigated have been used at temperatures between 2,000° to 4,000° K.

Tungsten has the highest melting point so far determined among the metals, and carbon is the only substance so far known with a higher temperature of fusion. We should therefore expect to be able to attain a greater intrinsic brilliancy with carbon than with tungsten, and this is borne out by experience. Tungsten melts[1] at 3,540° K and carbon can be heated to about

[1] I. Langmuir.

4,000° K, so that from this difference in temperature it might be expected that carbon would be the most efficient lamp filament. The candle-power per square millimeter of the crater of a carbon arc is about 130, and for the same surface of tungsten at its melting point, about 70.

When, however, it is attempted to run a carbon filament at the same temperature as one of tungsten, it is found that the carbon evaporates so much more quickly that the life of the lamp is very short in comparison with a lamp containing a tungsten filament. Hence though the melting point of carbon is so much higher than that of tungsten, the vapor pressure is also very much greater, so that the bulbs containing carbon filaments blacken more rapidly, and the filaments burn out much sooner than those made of tungsten.

Carbon boils before the melting point is reached, at about 4,000° K, while tungsten melting at 3,540° K boils at 5,100° K. The vapor pressure of tungsten at 2,400° K, about 1 watt per candle, is 8×10^{-10} millimeters of mercury, while that of carbon at the same temperature is probably about 3×10^{-3} millimeters. All other substances so far tried have either a lower melting point than tungsten or else their high rate of evaporation puts them at a disadvantage in comparison with this metal.

The third factor noted above as of importance in its bearing upon the efficient generation of light is the question of the quality of the light emitted by materials at definite temperatures. All bodies depart more or less from the ideal radiator or black body, the latter being the ideal substance which completely absorbs all radiation falling upon it, and consequently emits more energy of every wave-length than any other body at the same temperature.

The intensity of energy radiated by a black body at any temperature may be calculated for each wave-length by Planck's equation

$$E = \frac{C_1}{\lambda^5} \frac{1}{e^{\frac{C_2}{\lambda T}} - 1}.$$

C_1 and C_2 being constants.

Substances differ from a black body in two ways, with respect

to quantity and quality of radiation emitted from a given surface. A gray body at a given temperature radiates only a fraction of the energy radiated by a black body at the same temperature. The fraction radiated, however, is the same for each wave-length. Hence at the same temperature as a black body, a gray body will operate at the same efficiency in watts per candle, and differs only in intrinsic brilliancy, the light emitted from unit surface being less than that emitted by the ideal radiator. Many substances however, radiate selectively; that is, they have a different degree of emissivity for different wave-lengths. From the standpoint of illumination, the ideal radiator would be a substance which would radiate all of its energy as light at the wave-length of the eye's maximum sensibility—0.55 micron. The nearest approach to this is the radiator of the firefly. Many metals also, while very far indeed from such an efficiency, do radiate a greater proportion of their energy in the visible spectrum than a black body at the same temperature. Measurements of the reflectivity of tungsten by Dr. W. W. Coblentz of the Bureau of Standards indicate that while tungsten emits 50 per cent. of the energy radiated in the visible spectrum by a black body at the same temperature, it emits a much smaller proportion in the infra-red. A tungsten filament will therefore emit as much light for the same energy input as a black body at a considerably higher temperature.

Carbon, on the other hand, radiates its energy in a distribution very similar to that given by the ideal black body, so that in order to operate a carbon filament at the same efficiency as one of tungsten, it would have to be maintained at a temperature about 100 deg. higher. This fact coupled with its comparatively high vapor pressure has put it at a marked disadvantage when competing with the metal filaments osmium, tantalum, and tungsten, as well as with the Nernst glower.

The maximum efficiency for white light according to Dr. H. E. Ives[2] is given by a black body at 6,000° K and corresponds to a specific consumption of 0.10 watt per candle. For the ideal yellow green light with no other radiation except this emitted, the specific consumption is about 0.015 watt per candle. If the

[2] TRANS. I. E. S., vol. V, p. 113.

efficiency of the most efficient monochromatic source is taken as 100 per cent., the efficiency of the most efficient white light is about 15 per cent., that of tungsten operating a 1.25 watts per candle is 0.9 per cent., and of a tungsten filament at 0.5 watt per candle, 2.5 per cent. It is thus very evident that there is yet a long way to go in the art of efficient illumination.

The superior qualities of tungsten as an incandescent filament as stated above are due to its high melting point, low vapor pressure, and selective radiation characteristics. The life of a tungsten lamp operating in vacuum at the ordinary efficiencies is usually considered to end when sufficient metal has evaporated from the filament and deposited on the bulb in a layer sufficiently opaque to reduce the candle-power to 80 per cent. of its initial value. It occurred to Dr. Irving Langmuir of the General Electric Company that this rapid evaporation might be prevented or at least considerably lessened by the introduction of an inert gas. Though similar suggestions had been made before, experimental work had always given negative results because the effect of several factors in the problem were not properly understood when they seemingly made the case appear hopeless. The production of a lamp with tungsten filament operating for a reasonable length of time at a specific consumption of 0.5 watt per candle and higher is described by Dr. Langmuir in the *Proceedings* of the American Institute of Electrical Engineers.[3]

The benefits resulting from the introduction into the lamp bulb of a gas which does not attack the filament are due to (1) the lessening of the rate of evaporation of the filament material so that for the same life the temperature of the filament may be considerably higher, resulting, of course, in greater intrinsic brilliancy; (2) the carrying of such material as does evaporate into the upper part of the bulb by means of the convection currents in the gas. When deposited thus, there is very little absorption of light in comparison with the loss which would occur if the deposit were distributed uniformly over the surface of the bulb.

The vapor pressure of the metal is not necessarily affected by the presence of the gas. The function of the latter is to reduce

[3] October, 1913.

the rate of diffusion of the evaporated particles away from the vicinity of the filament so that a condition more nearly approaching equilibrium is maintained between the material leaving the filament and that returning to it, than is the case in vacuum where the tungsten atoms which evaporate go straight to the bulb where they remain. The "escaping tendency" of the metal is unaffected, but the ease with which the vapor can leave the neighborhood of the hot wire is very seriously interfered with. For instance, compare the case of water which if suddenly introduced into a good vacuum will evaporate so rapidly that it is frozen by the heat absorbed in the process. In air, however, though its vapor pressure is about 2 centimeters at ordinary temperatures, it requires a long time for a space to become saturated with vapor so that the concentration is uniform throughout.

The gases which have been most thoroughly investigated up to the present time with respect to their application in lamps are nitrogen, argon, and mercury-vapor.

The gas-filled type of lamp differs from the lamp with the filament operating in high vacuum in the following ways: (1) color of light emitted by the filament; (2) shape of filament; (3) volt–ampere–candle-power characteristics.

COLOR.

The reduction in the rate of evaporation of the filament by the gas enables attainment of a much higher temperature than is possible with a filament in vacuum. In nitrogen it is possible to maintain a tungsten wire at from 400-600° C. above the temperature of a filament operating in vacuum at 1 watt per candle. In mercury vapor, filaments may operate at a temperature of between 3,100° and 3,200° K. Of course this means that the light is very much whiter than that of ordinary incandescent lamps. As the temperature of a substance increases the radiation increases more rapidly in the shorter wave-lengths, and the wavelength of maximum emission is displaced more and more towards the blue end of the spectrum as described by Wien's displacement law:

$$\lambda_{max.}\ T = \text{constant.}$$

The relation between the color of filaments operating at different temperatures and average daylight is shown in Fig. 1. The

curve for average daylight, black body radiation at 5,000° K, and for the tungsten filament operating at 1.25 watts per candle, are in accordance with the data collected by Dr. H. E. Ives.[4]

The significance of these curves is perhaps best shown if they are used in connection with the luminosity values for each wave-length to determine the efficiency of white light, which would result if absorbing screens were used to correct the light emitted by the filament to the same distribution as in average daylight. An ideal screen, correcting from a wave-length of 0.43 μ, would

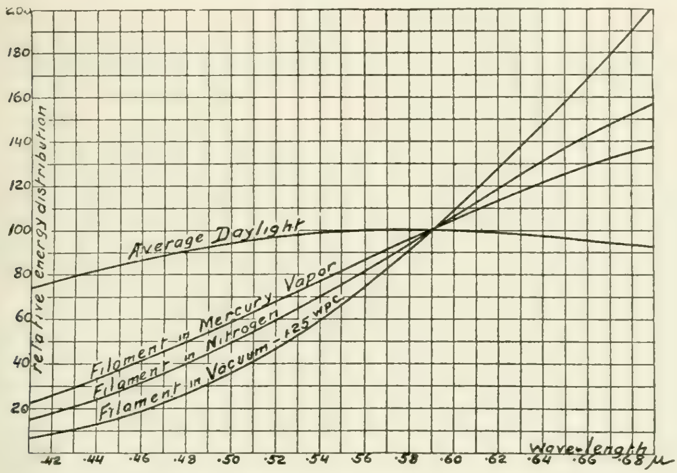

Fig. 1.—Relative energy distribution of radiation from tungsten filaments at different temperatures.

give approximately the following daylight specific consumption for filaments at different temperatures:

Tungsten in vacuum 1.25 w.p.c....	7½	watts per horizontal candle
Tungsten in nitrogen	1¾	watts per horizontal candle
Tungsten in mercury vapor.......	1	watt per horizontal candle

It is very difficult, however, to obtain an ideal absorbing screen. Glass is the most suitable medium from the standpoint of permanency, but it is very difficult to properly combine the necessary colors in such a way as to secure the highest degree of transmission of the desirable light. Great progress has been made in this direction, however, through the efforts of American glass makers who have made very thorough scientific investigations in

[4] TRANS. I. E. S., vol., V, p. 189.

the field of colored glasses, and a set of glasses has been obtained which gives a "daylight" specific consumption of about 2.5 watts per candle with the nitrogen-filled type of lamp. The intrinsic brilliancy of the high current nitrogen-filled lamp is about 1,200 candle-power per square centimeter, that of a filament in mercury vapor between 2,500 and 3,000 candle-power.

The visible radiation emitted from these lamps has the same energy distribution as a black body, and there is not the slightest trace of luminescence from the surrounding gas.

SHAPE OF FILAMENT.

The most favored form of filament for the gas filled lamp is the tightly coiled helix.

Early in the development of these lamps it was found that the life of a lamp increased very materially with the size of the filament, and that the relative loss by conduction of heat through the gas was very much less with filaments of large diameter. Unless very low voltages are used, however, the power consumed with the larger wires is so great that very large units are necessary. And low voltage units are objectionable on account of the cooling effect of the leading in wires then becoming comparatively great. The helically wound filament, however, gives a comparatively large effective diameter to minimize the energy loss by heat conduction through the gas, and allows a much heavier wire to be used for the same energy input since the wire only radiates energy from the exposed surfaces of the spiral.

The chief advantage of helical winding lies in the diminished loss of energy by conduction of heat through the gas. Dr. Langmuir in his investigation on convection and conduction of heat in gases[5] found that his experimental results, which dealt largely with the energy losses from heated wires of very different sizes in various gases, could be comparatively simply expressed mathematically if a stationary film of gas were assumed in proximity to the wire through which conduction only occurred. The thickness of this film was found to be independent of the temperature and to vary with the diameter of the wire according to the formula

$$b \ln \frac{b}{a} = 2B.$$

[5] *Phys. Rev.*, 34, p. 401, 1912.

B being a constant for any gas and equal to the thickness of film for a plane surface, b diameter of cylinder of gas, a diameter of wire. B was found to be equal to 0.170 inch for air at atmospheric pressure whence the film diameters for wires of varying size are as follows:

Wire diameter (mils.)	Film diameter (mils.)
1	78
2.5	95
5	110
10	130
25	175
50	225
100	300
200	435

It is thus seen that a tenfold increase in the radiating surface of the wire is accompanied by only a twofold increase in the diameter of the cylinder of gas which is dissipating the energy lost by conduction. This effect coupled with the fact that the "heat flux" decreases more rapidly with the smaller wires, due to the greater curvature, leads to the explanation of why the heat loss is almost as great with a small wire as with a larger one. In fact with small wires it is very nearly true to say that the actual heat loss per centimeter of *length* is independent of the diameter. Hence, of course, the loss relative to the energy radiated becomes much less as the diameter of the filament is increased, since the radiated energy is proportional to the diameter of the wire. Fortunately, too, a closely wound spiral has been found to be practically the equivalent of a wire of the same diameter with respect to these conduction losses.

Table I taken from Dr. Langmuir's paper[6] illustrates the magnitude of this effect as well as the advantage of being able to increase the temperature of the filament.

The current taken by a straight wire is about 20 per cent. greater than that required by the same wire at the same temperature if closely coiled. This of course, means a difference of approximately 40 per cent. in the watts. At the same temperature, however, the efficiency of the straight and helical filaments is the same. There can be no "bottling up" of light in the interior part

[6] *Trans. A. I. E. E.*, October, 1913.

of the spiral without a corresponding enclosure of the rest of the accompanying radiation in the infra-red and ultra-violet.

TABLE I.—SPECIFIC CONSUMPTION (IN WATTS PER CANDLE) OF TUNGSTEN FILAMENTS IN NITROGEN AT ATMOSPHERIC PRESSURE, AS COMPARED WITH THAT IN VACUUM.

Absolute temp.	In vacuum	Diameter in inches 0.001	0.002	0.005	0.010	0.020	0.050	0.100
2400°	1.00	4.80	3.13	2.02	1.59	1.35	1.18	1.11
2600	0.63	2.53	1.71	1.14	0.93	0.81	0.72	0.69
2800	0.45	1.54	1.07	0.74	0.62	0.53	0.50	0.49
3000	0.33	1.00	0.71	0.50	0.43	0.39	0.36	0.35
3200	0.26	0.70	0.51	0.37	0.33	0.30	0.28	0.27
3400	0.21	0.52	0.39	0.30	0.26	0.24	0.23	0.22
3540	0.20	0.45	0.34	0.27	0.24	0.22	0.21	0.21

SPECIFIC CONSUMPTION (IN WATTS PER CANDLE) OF TUNGSTEN FILAMEMTS IN MERCURY VAPOR AT ATMOSPHERIC PRESSURE COMPARED WITH THAT IN VACUUM.

2400	1.00	2.30	1.77	1.38	1.24	1.16	1.10	1.07
2600	0.63	1.30	1.03	0.84	0.78	0.72	0.67	0.67
2800	0.45	0.84	0.68	0.57	0.53	0.50	0.48	0.47
3000	0.33	0.57	0.47	0.40	0.36	0.36	0.35	0.34
3200	0.26	0.41	0.35	0.30	0.28	0.28	0.27	0.27
3400	0.21	0.32	0.28	0.25	0.23	0.23	0.22	0.22
3540	0.20	0.29	0.25	0.23	0.22	0.21	0.21	0.20

It can be readily noticed, however, especially if a magnified image be thrown upon a screen, that the interior of the spiral where it can be seen between the adjacent coils, appears to be about twice as bright as the outside. This is due to the fact that an artificial "black body" is formed by the turns. Tungsten emits only 51.4 per cent. as much energy in the visible spectrum as a black body at the same temperature. Consequently it reflects 48.6 per cent. of the light falling upon it.[7] The inside of a turn in addition to emitting its own radiation may reflect nearly 50 per cent. of the light falling upon it from the opposite turn, and if the opening were sufficiently narrow in V-shape, enough repeated reflections and absorptions might occur to make the surface appear as bright as a black body at the same temperature. It might be supposed that the inside of the spiral would be hotter than the outer surface, but calculations based on the known heat

[7] Kirchhoff's law states that the energy radiated by a body at any temperature is prodortional to the absorptive power of the body at that temperature.

conductivity of tungsten place the limit of difference at less than 1 degree Centigrade.

Since the radiation which is emitted from the interior approaches in quality that of a black body, its efficiency with respect to light is not quite as high as the selective radiation from the exterior. However, the effect is so small that it is hardly appreciable.

VOLT—AMPERE—CANDLE-POWER CHARACTERISTICS.

The relationship between the volts, amperes, and candle-power of gas-filled lamps differs from that of lamps with good vacuum in the effect of the introduction of a medium which will cause a

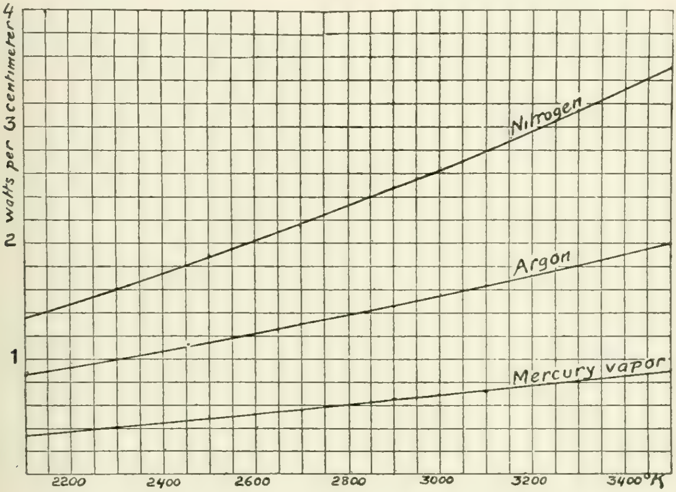

Fig. 2.—Heat conductivity of gases in watts per sq. cm. from indicated temperature to 20° C.

loss of energy from the filament depending for its magnitude upon several factors. These are: (1) kind of gas introduced; (2) amount of gas introduced; (3) size of filament.

DIFFERENT GASES.

The three gases which may be most readily used in lamps are, nitrogen, argon, and mercury vapor. Curves showing the heat conductivity of each in watts per square centimeter at different temperatures are shown in Fig. 2. These curves show the watts per centimeter conducted between the temperature indicated and

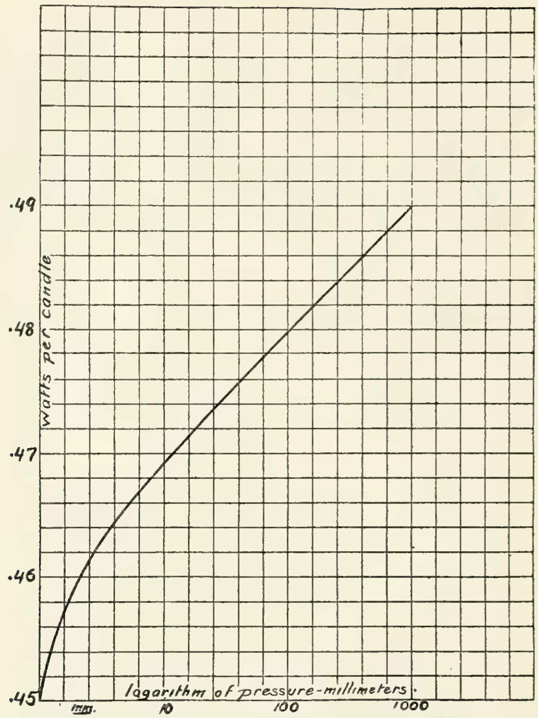

Fig. 3.—Variation of specific consumption with pressure of gas at constant temperature. 20 ampere spiralled filament at 2800° K.

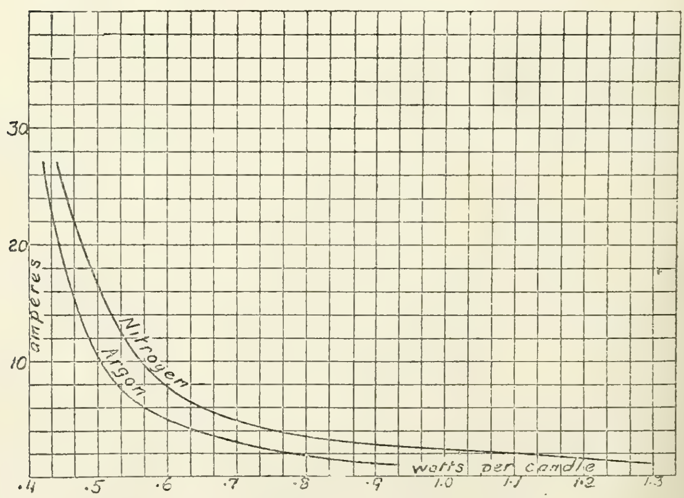

Fig. 4.—Variation of specific consumption with size of filament necessary to maintain uniform life.

room temperature. A marked difference is shown between the different gases, and the advantage of using argon in preference to nitrogen, and of mercury vapor to either is at once apparent if the difference in heat conductivity *alone* be considered. The difference between the effect of mercury vapor and nitrogen is shown in Table I; between nitrogen and argon in Fig. 4.

PRESSURE OF GAS.

It has been found that the rate of evaporation of tungsten in nitrogen is not appreciably reduced by pressures of gas as low as 1-millimeter (of mercury column). At 10 millimeters pressure, however, it is reduced to about 1/10 of its value in vacuum, and at 1,000 millimeters to about 1/100 of its rate in vacuum. Hence the higher the pressure of gas the longer the life of the lamp. On account of the increased pressure of the gas on lighting the lamp, and the inability of the ordinary glass bulb to withstand much pressure, the amount of gas initially introduced is somewhat less than atmospheric pressure, and may vary considerably with different styles of lamps. However, from Fig. 3 it will be seen that between ⅕ and 1 atmosphere, the heat conductivity of the gas affects the watts per candle so little that the efficiency of a filament operating at the same temperature at the different pressures is only very slightly affected.

VARIATION OF CHARACTERISTICS WITH SIZE OF FILAMENT.

The life of a filament to its burning-out point, or to a given percentage reduction of its diameter, has been found to be at least proportional to the diameter of the wire. There is also some evidence to indicate that for very small wires, it may be proportional to the square of the diameter. The first result is to be expected because wires of varying diameter may be expected to fail when evaporation of material has occurred to such an extent that the diameter is reduced by a uniform percentage in each case. A 10 per cent. reduction in diameter is usually sufficient to cause a filament to burn out. That is, if with a filament 10 mils in diameter, ½-mil in depth has been removed by evaporation the lamp may be expected to fail by burning through at some point where a slight irregularity in the wire gradually accentuated causes excessive evaporation. Since, however, the

rate of evaporation is proportional to the surface of the filament only, it will take twice as long to evaporate a layer 1 mil in depth, or 10 per cent. of its diameter, from a wire 20 mils in diameter. The latter filament will therefore have twice the life of the 10-mil wire. If in addition, however, it is realized, in analogy with loss by heat conduction, that owing to the less curvature of the larger wire, the tungsten vapor has to diffuse twice as far from the 20-mil wire as from the 10-mil wire in order for its concentration to be reduced to the same extent, it is apparent that another factor in favor of the larger filament comes into play. The combined effects may thus result in the life of a filament being proportional to the square of the diameter. This result has not yet been fully demonstrated experimentally because various irregularities have entered into the somewhat meager data to such an extent as to mask any such effect.

One of the most important relationships in connection with gas-filled lamps is the relation between size of filament, efficiency and life. For practical purposes it is of most interest to consider how the efficiency varies with the size of filament if the life of the various filaments is constant. For the present practise is to compare lamps on the basis of a uniform life performance irrespective of the type involved.

As pointed out above, filaments of smaller diameter, operating in a gas, when at the same temperature as the larger wires, run at a lower efficiency due to the greater relative loss of energy through the gas in the case of the smaller filaments. Thus from Table 1 it may be seen that a 20-mil wire in nitrogen at atmospheric pressure operates at 0.53-watt per candle when the temperature is 2,800° K. A 1-mil wire at the same temperature, however, is only at 1.54 watts per candle. As already shown, however, since the life of a filament is at least proportional to its diameter, the temperature of the smaller filament must be very considerably lowered in order to maintain a uniform life.

These two facts indicate at once, that in lamps of the gas filled type, the efficiency of lamps operating for the same life will vary very greatly with the size of filament and consequently the current rating of the lamp. Thus from Fig. 4 it is seen that in

order for a 1-ampere lamp to last as long as a 20-ampere lamp at 0.47 watt per candle the specific consumption of the former will have to be lowered to about 1.3 watts per candle.

Fig. 4 shows the relationship between lamps of different current ratings and the specific consumption at which they must be run to give the same life. There is a striking difference in the effect of improvement in the heat resistivity of the gas between the high current filaments and those of smaller size. With the 25-ampere size the substitution of argon for nitrogen only means an increase of 5 per cent. in the efficiency, while with the 1-ampere lamp it means an increase of 30 per cent. At very low currents the lamp filled with nitrogen can not be maintained at as good an efficiency as the vacuum lamp for an equal period of time. Hence the presence of such a gas with very small filaments results in a poorer lamp, and this effect has discouraged many investigators from finding any use in the introduction of gas into a lamp bulb. Even with the less conducting argon, extremely small wires can not be operated with a sufficient gain to make the use of argon universal in its application to lamps, but a great improvement in the efficiency of the smaller current lamps can be made in comparison with the nitrogen-filled type. The effect of a gas of less heat conducting power, of course, is much more noticeable with the smaller wires since the greater part of the energy loss then takes place through the gas, while with the larger diameter filaments the loss through the gas is only a small percentage of the radiated energy.

For small changes in temperature, with current ratings of 6 amperes and higher, the volt–ampere–candle-power characteristics follow the vacuum characteristics sufficiently closely for ordinary working. With lower currents, however, where the heat loss through the gas becomes more appreciable, the departure becomes more serious. We then have to consider the effect of the superposition on the radiant characteristics of the filament the effect of the gas with its very much lower temperature coefficients.

APPENDIX.

For gas-filled lamps in particular, the advantage of referring all the varying characteristics of a lamp filament to a temperature

basis cannot be too strongly emphasized for experimental work. Even if the absolute value of the temperature scale be in doubt, it gives accurate relative results which can very simply be transferred to a new scale. Above all other variables it is the one most intimately concerned in the behavior of an incandescent substance, and consequently the most important factor in the interpretation of results.

In the research laboratory of the General Electric Company, Dr. Langmuir has adopted intrinsic brilliancy, or candle-power emitted from unit surface, as the criterion of temperature. He has deduced the following formula giving the relation between temperature in degrees Kelvin, and the intrinsic brilliancy, H, in international candle-power per square centimeter of projected area:

$$T = \frac{11,230}{7.029 - \log. H}.$$

For substances other than tungsten, the quantity H is multiplied by the ratio of the emissivities of the substance in question and that of tungsten.

The determination of the temperature of a straight or a hair-pin filament is then very easily carried out by obtaining the candle-power of the filament viewed from the photometer head through a slit placed close to the lamp so that only the part of the filament which is at a uniform temperature is to be seen. The parts of the filament cooled by the leads are thus screened off. Knowing the distances of the photometer and screen from the filament it is of course a simple matter to find the length of filament visible, and the diameter being known, the intrinsic brilliancy may be found. The diameter is most accurately found by weighing known lengths of filament and calculating the result using 19.4 as the density of tungsten.

Once having a fixed standard of temperature, however, calibrated in this manner, it is very much more convenient to depend upon color as the measure of temperature. This method has been in use in several laboratories, and has been fully described by Langmuir and Orange.[8] By the use of the ordinary Lummer-Brodhun photometer screen it has been found easy to color-match

[8] *Trans. A. I. E. E.*, October, 1913.

one filament to another to within 5 deg. in temperature when the illumination is good, and the temperature between 2,000°-3,000° K. The advantage of the method over others consists in the fact that it is independent of size and shape of the filament under investigation as long as the bulb remains clear, and is therefore applicable to all types of lamp without the use of screening apparatus.

It is not advisable, however, to operate the filament of a standard lamp above 2,300° K, since in vacuum blackening of the bulb occurs very rapidly at higher temperatures. Fortunately, however, the color corresponding to higher temperatures may be obtained by using a blue screen to absorb the red end of the spectrum in the light emitted by the standard which then gives an integral color effect similar to that produced by the displacement due to increased temperature.

A single standard lamp operating at a definite voltage may thus be used with several screens of different intensities for various temperatures. The screens, of course, should be calibrated for transmission with a flicker photometer, and with the lamp at the voltage at which it is to be run, since the transmission coefficient will vary for filaments at different temperatures.

It may be shown both theoretically and experimentally that the following relationship holds:

$$\frac{1}{T} - \frac{1}{T_1} = a + b + c, \text{ etc.,}$$

where T is the temperature of the filament viewed through the screens A, B, C, etc., and T_1 the temperature of a filament which matches the other in color, and *a, b,* and *c,* constants for the screens A, B, and C.

Screens of a brownish color to apparently reduce the temperature of the filament under investigation to a lower value may also be used. These have the advantage of being used on that side of the photometer where there is more light to spare, and the disadvantage of a variable transmission coefficient as a color match is departed from.[9]

[9] Suitable screens of blue glass ground and polished on both faces may be obtained in six different intensities from the American Optical Company, Cambridge, Mass., or dyed gelatine screens, both blue and brownish in color, enclosed in optically good glass, from the Eastman Kodak Company, Rochester, N. Y.

The reduction of the different filament characteristics to a temperature basis is a simple procedure. For given the relation between candle-power and temperature, with a new lamp or type of lamp the procedure is as follows:

The lamp is set up on the photometer bench and color-matched with the standard lamp and screen to a convenient temperature defined by that color. Volts and amperes are then measured as usual. The temperature (or voltage) of the filament is then raised or lowered as desired and volts, amperes, and candle-power measured at stated intervals. From the ratio of candle-power at any of these points to the candle-power at the standard temperature, the temperature at any point may be determined from the temperature–candle-power plot. The volts, amperes, and efficiency may then be plotted with respect to temperature, and of course with respect to each other if so desired.

It would aid very greatly in the correlation and interpretation of experimental data if the various laboratories making investigation along these lines would use a common temperature scale for the expression of their results. Little if any physical significance is attached to any other variable when dealing with the complex factors involved in gas-filled lamps.

DISCUSSION.

MR. W. E. FORSYTHE: Mr. Mackay says on the eleventh page of his paper that, while the radiation from the inside of the spirals approaches in quality that of a black body, the effect of this added radiation is small. How much this may change the character of the radiation may be shown by color matching a type C lamp with an ordinary vacuum lamp and comparing their black body temperatures.

I have found that if an ordinary tungsten lamp, operated at a black body temperature of about 2,055° K. was color matched with a particular type C lamp, the latter would have to be operated at a black body temperature of about 2,090° K. as measured on the outside of the spirals. This shows that the radiation from the inside and from the outside of the spirals are of different character.

In addition I want to second what Mr. Mackay says in the

Appendix as to referring all the varying characteristics of a lamp filament to the temperature. I would like to suggest that this temperature scale be based on Wien's radiation law and that the temperature be measured with some form of optical pyrometer, preferably the Holborn-Kurlbaum.

Using the optical pyrometer one would get directly the black body or apparent temperature, which if necessary could be reduced to true temperature by assuming certain unproven laws concerning the optical properties of the metal under consideration. However, the black body temperature would give a definite relation which would enable different observers to compare their results. All that would be necessary in order that each should get the same black body temperature under the same condition of operation, would be for each one to use the same kind of glass to obtain the monochromatic radiation and extend the temperature scale by means of Wien's equation in the same manner. Later, these black body temperatures could be reduced to true temperatures by making use of relations obtained by a V-shaped filament of the metal[1] or when more is known concerning the optical constants of metals at high temperatures, they could be directly reduced to true temperatures.

Mr. A. G. Worthing: Mr. Mackay stated that the difference in temperature between the inside and the outside of a spiral filament is less than a degree centigrade in the regular, large-sized, gas-filled lamps. This has been questioned. A moment's consideration shows that this temperature difference must be less than that occurring in a tubular filament of the same outer surface temperature whose external and internal diameters are the same as the corresponding diameters of the spiral. For such a tubular filament, the computations are simple. Determinations of the heat conductivity of tungsten at high temperatures which have been made at the Nela Research Laboratory justify Mr. Mackay's statement.

In speaking of the advantages of the spiral filament, it has been noted that, for a given filament temperature, the gas loss approaches in actual amount that for a hollow cylindrical filament related to the spiral as noted above. A distinct advantage of the

[1] *Astrophysical Journal*, **37**, 1913, p. 380.

spiral form over such a cylindrical form exists, however, when one considers the end losses due to the cooled junctions with the lead-in wires. In low voltage lamps these losses may amount to many per cent. For lamps of equal wattage, computations show losses for the cylindrical filament to be about twice as great as for the spiral filament.

Mr. J. B. Taylor: A previous speaker has questioned the small difference in temperature between the inside and the outside of a helical filament. That there is no marked difference in color can be easily checked by projecting an enlarged image of the filament on a screen and measuring the surface brightness with a lumeter or other portable photometer. Color match is as readily made on the inside as on the outside surface of the helix.

Mr. L. J. Lewinson: I wish to urge the importance of m. s. cp. measurements in the case of gas filled tungsten lamps. In view of the varying ratio of m. s. cp. to m. h. cp. met with in the lamps as manufactured at present, such measurements are absolutely essential. Furthermore, due to the location of the discoloration of the bulb as the life progresses, as described by Mr. Mackay on the fifth page—the m. s. cp. falls off more rapidly than the m. h. cp.

While not necessarily advancing the 80 per cent. criterion as a proper one for lamps of this type, it may be interesting to note that experience with lamps manufactured in the recent past shows the average life to 80 per cent. of initial m. s. cp. to be considerably less than that to 80 per cent. of initial m. h. cp. of the same group.

EXPERIMENTS WITH COLORED ABSORBING SOLUTIONS FOR USE IN HETERO-CHROMATIC PHOTOMETRY.*

BY HERBERT E. IVES AND EDWIN F. KINGSBURY.

Synopsis: A yellow solution is described which, used in various concentrations over standard or test electric incandescent lamps eliminates color differences. A calibration curve is given showing transmissions of various concentrations obtained by a carefully worked out photometric method. Much care must be taken in the choice and use of tanks to contain the solution and details of precautions are discussed.

INTRODUCTION.

Under the title "A Practical Solution of the Problem of Heterochromatic Photometry[1]," Prof. Ch. Fabry published a most valuable contribution to the problem of colored light photometry. He pointed out that the much desired condition of reducing all photometry to that of lights of the same color ought to be solvable by the use of colored absorbing solutions, reproducible from specifications at any time or place. He discussed the character of absorption which would be most desirable and described two experimentally developed solutions which have the postulated characteristics.

The advantage of possessing such absorbing media is obvious to those who have devoted study to this problem. Reproducible everywhere, making it possible for any observers, no matter what their defects of vision and no matter what type of photometer they use, to calibrate their working standards of various colors in agreement with the standardizing and other laboratories, such media would banish the problem of heterochromatic measurements from many lines of work.

As Prof. Fabry clearly recognized, however, the development of appropriate solutions is only half the problem. The other half

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

[1] TRANS. I. E. S., vol. VIII, p. 302.

is the determination of their transmission by officially approved and established photometric procedure. Such a procedure did not exist at the time of Prof. Fabry's work, so that the transmission values given by him are but approximate. Indeed, such an established procedure does not even now exist. But a consistent scheme of colored light photometry developed on the basis of an investigation of the problem by one of the writers is in use at this laboratory† and suggested the desirability of establishing by it the transmission values of these solutions. Needless to say it is our hope that the method of colored light photometry here used, or one consistent with it, will sooner or later be adopted generally; so that the results of this present work will be of permanent value.

EXPERIMENTAL WORK.

The account of the experimental work, to follow, will treat the subject topically rather than chronologically. In the actual work various unexpected difficulties were encountered, often after a great deal of labor had been expended, necessitating some repetition of apparently completed work. These set-backs we have endeavored to turn to good account by the emphasis we give to certain details which might easily have been overlooked had no difficulties developed.

Tanks for Holding Absorbing Solutions.—The precision attainable in the use of solutions in transparent walled tanks is *absolutely* dependent on the degree of transparency and on the uniformity of the tanks. Our first tanks were of the type shown in Fig. 1, of glass, with glass faces cemented on, and furnished with ground stoppers. The space between faces was, in the first sample obtained from the dealer, accurately one centimeter. In a subsequent order of several cells, variations of as much as ten per cent. were found. Thereupon we placed a special order for three to be made exactly one centimeter thick. These when received were accurate in thickness, but the glass faces were of a pronounced green tinge. The manufacturer, on another attempt, provided faces of clear white glass, and preparations were made to use these. It developed, however, that the transmission of these cells, holding clear water, differed by as much as *five per*

† Physical Laboratory, United Gas Improvement Co., Philadelphia, Pa.

cent. Furthermore, the difficulty of cleaning them was such that, without the most extreme care, variable differences of transmission would creep in. These troubles necessitated a thorough study of glass tanks.

The observed differences in transmission were finally ascribed to two causes: one, the presence of coloring material in the glass and, two, the condition of its surface. White glass may be either clear optical glass, or it may be a cheap glass containing iron, which imparts a green color, and manganese, which imparts a purple color, used to offset or decolorize the glass. The result is a white or colorless glass whose transparency is lowered and

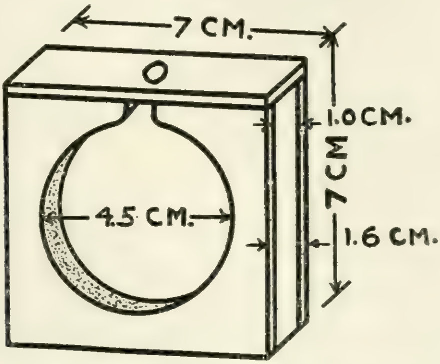

Fig. 1.—Absorption cell, first type (unsatisfactory).

whose transmission is different for different colors. As to the surface conditions, these vary with age and use. Some glass becomes dull by exposure, through a species of decay, and frequent cleaning produces fine scratches which lose light by diffusion.

The cells finally used are represented by Fig. 2. The central solid glass frame is accurately ground to one centimeter thickness. The two faces are not cemented on, but are easily removable for cleaning. After cleaning with nitric acid and distilled water they are merely laid in close contact with the glass frame and held in position with rubber bands, while a seal of paraffine is run around the edge with a hot metal point or spoon.

Specially selected clear white glass was obtained from a prominent optical company, who gave the glass a thorough polish

before delivering it. This glass was then tested for selective absorption through the spectrum by settings on the photometer made through a set of six approximately monochromatic color screens, no difference of transmission being detected.

After taking these precautions the two cells used in the investigation were found to be absolutely interchangeable. Both received the same cleaning treatment during the investigation and on frequent tests showed that their entire equivalence was being maintained.

Search for Solutions.—As Prof. Fabry points out, the most generally useful solutions would be those which would transform the light of an incandescent solid at one temperature to equivalence with that at another. A generally yellow solution is called

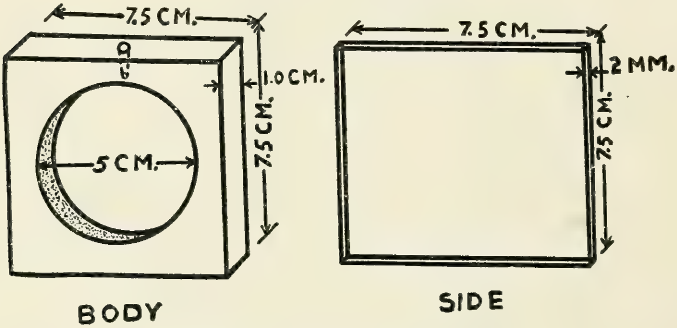

Fig. 2.—Absorption cell, second type (satisfactory).

for to reduce the apparent temperature (judged by color) of a black body; a generally blue solution to increase it. Perhaps the most interesting part of Prof. Fabry's communication is his demonstration that absorbing media can be postulated which shall, by mere change in concentration, take up any color difference produced by differences in temperature in an incandescent solid. The characteristic of such solutions is that the opacity shall be a function of wave-length represented by the equation:

$$\text{log. opacity} = -\frac{A}{\lambda} + B.$$

The two solutions found suitable by Prof. Fabry were, for the yellow, a solution of iodine in potassium iodid, and for the blue,

a solution of copper sulphate in ammonia. These he used with the Carcel lamp and found them adequate to take care of all colors from the tungsten lamp to the Hefner. In combination these solutions, being in color practically two of the three subtractive primary colors, matched the color of the Welsbach mantle and other illuminants which differ more or less from the black body.

Part of our original plan was to determine the transmissions of these solutions in varying concentrations, used with the "4-watt" carbon lamps which are the standards for this country. A thorough trial of both the yellow and the blue solutions soon showed us that our task was much greater than we had anticipated, because neither solution did what was required over the present existing range of illuminant colors. The Carcel lamp, with which Prof. Fabry worked, is much whiter than the 4-watt carbon lamp, and when his work was done the whitest black body illuminant was the 1.25-w. p. c. tungsten lamp. Used over the color range from the Hefner to the nitrogen-filled tungsten, these solutions proved inadequate, as at the closest approximation a very pronounced color difference remained outstanding. We had, therefore, to find, as well as to measure, our solutions.

Constitution and Method of Preparing Yellow Solution.—Some of the physical characteristics desirable in a photometric absorbing solution, apart from its spectrum distribution of absorption, may be mentioned. They are most of them obvious. The solution should be a stable chemical; it should be made from chemicals of definite reproducible character; it should be as little affected as possible by temperature changes; it should be unaffected by light. Many promising substances from the standpoint of color were rejected because of failure to meet all these conditions. Some, such as ferric chloride, precipitated after a short lapse of time; other iron salts faded in the light; ammonicial solutions changed color by unpreventable evaporation; certain chemicals were so deliquescent that their definite weighing was problematical. The large number of organic dyes were ruled out as not accurately definable. In all, probably five hundred different salts and combinations were tried. Finally a very satisfactory yellow solution was developed which would take up

incandescent lamp colors from the 4-watt to the most efficient tungsten and down below the Hefner lamp color.

The composition of the solution is as follows: 100 grams c. p. cobalt ammonium sulphate; 0.733 grams c. p. potassium dichromate; 10 c. c. 1.05 gravity c. p. nitric acid; distilled water to make one liter of solution at 20 deg. C.

The method of preparing the solution is important though simple. The two salts should be dried in an oven at about 70 deg. C. for half an hour, allowed to cool and then weighed to an accuracy of one part in one thousand. Neither one seems to absorb enough water, even in damp weather, to affect it seriously, but artificial drying insures a uniform solution. The double salt of cobalt was selected mainly because of its admirable behavior in this respect. Dissolve the sulphate in about four fifths of the total water required, to which the required amount of nitric acid should be added. In a separate dish dissolve the dichromate in a little water. When both are dissolved completely, pour the dichromate into the cobalt ammonium sulphate, plus the acid, and add enough pure water to make the required volume. One should be careful to rinse the dichromate dish completely and to wash off any stirring rods used. In making smaller concentrations than 100 per cent., appropriate quantities of the salts may be taken, or the 100 per cent. diluted with pure distilled water. Care should be taken not to mix the dichromate and sulphate without the acid being present, otherwise a precipitate is liable to form more or less rapidly, dependent on the conditions. If after several days a flocculent precipitate forms it is a pretty sure sign that the acid has been omitted.

At first acid thorium nitrate and uranyl nitrate were used to keep this precipitate from forming; but the acid is simpler and seems to be just as good. Combinations of metallic salts and potassium dichromate are used quite extensively in separate solutions. It is of course better to have one solution, which can be affected by keeping it slightly acid.

The solution referred to above seems to be free from any rapid fading, as samples which have stood in a strong light and warm room for several weeks have not shown any detectable change.

All the ingredients are easily procurable. The only one likely to cause delay in securing is the sulphate. This is easily made, if desired, by mixing properly dried cobalt sulphate and ammonium sulphate in gram-molecular proportions, dissolving in just enough boiling water and allowing it to cool, when dark red crystals will separate out which can be collected and dried on filter paper. Good c. p. analyzed chemicals should be used. Imported brands are not essential.

Method of Using Solution.—The two Fabry solutions were intended to be used uniformly on the side of the auxiliary standard lamp, using the substitution method. First a tank filled with clear water was placed between the photometer and the auxiliary standard or comparison lamp, then the illumination on the photometric screen was determined by a setting upon a standard lamp. In this setting there is no color difference, since the comparison lamp is the color of the standard. The standard is now removed, the differently colored light put in place of the standard, and on the comparison side is introduced a tank with the appropriate colored solution. A second setting is made, again with no color differences, but in the calculation of candle-power the established value of the solution transmission is introduced. Whether using the solution in this way or in the way about to be noted, it is always desirable to alter the relative distance of the lamp on the opposite side to the solution; by so doing the necessity of correcting for the tank thickness is avoided.

In order to use the solution always on the comparison lamp side, which is the most desirable way, it is necessary with the new high temperature filaments to have a blue solution. Up to the present writing a satisfactory blue solution has not been found. It seemed to us desirable to carry through our experiments on the calibration and use of solutions with the one yellow solution rather than to delay longer. Another consideration also received weight. It happens that most of the newer high temperature units have also high candle-power. It is consequently undesirable to be forced to cut down the intensity of the comparison lamp illumination. A yellow screen on the high intensity side has certain advantages. The disadvantage of working on

the test lamp side is that the total transmission of an absorbing medium is dependent on the character of the incident light. The same solution has a different transmission for a carbon lamp at 4 watts per candle and for a tungsten at 1 watt per candle. We have measured and here give the transmission of our yellow solution, used both on the comparison lamp side, for measuring yellow illuminants, and on the test lamp side, for measuring whiter ones; but when used in the latter position it is clearly to be understood that the transmission values apply only to the type of radiation exhibited by tungsten filaments when at such a color that the interposition of the solution produces 4-watt color. The one solution then makes it possible to work either way from the 4-watt color, with certain restrictions in working with the whiter illuminants.

We have made our calibration solely on the basis of concentration, rather than on thickness of solution, for the reason that the concentration can be varied with great accuracy by careful weighing, whereas it is difficult to vary thickness without increasing the amount of glass and auxiliary apparatus, and difficult to protect the solution from evaporation. If Beer's law holds for the solution, as it apparently does to a close approximation, thickness and concentration are interchangeable.

Method of Calibration.—The instrument used in the measurement of the yellow solution was a specially-constructed flicker photometer, of which a diagram is shown in Fig. 3. This instrument is fully described in an article published in the *Physical Review*.[2] Suffice it here to say that it makes possible measurements of considerable precision under the photometric conditions of illumination and field size specified by one of the present writers.[3] All the measurements are made with the same brightness of field—that corresponding to an illumination of 25 meter-candles on a white surface, the field being 2° in diameter. More will be said below in comment upon the photometric procedure.

Of equal importance to the choice of photometric method is the selection of observers. A very large number is necessary in order

[2] Ives and Brady, New Design of Flicker Photometer; Sept. 1914.

[3] Ives, Herbert E., Photometry of Lights of Different Color; *Philosophical Magazine*, 1912.

to secure results which may be called those for an average eye. In the present investigation it was possible to secure a group of six to eight observers selected from a previously examined group of twenty-five in such manner that their mean was substantially that of the large number. This was made possible by a parallel study now under way in which it is necessary to determine the transmission of a monochromatic green solution. Twenty-five

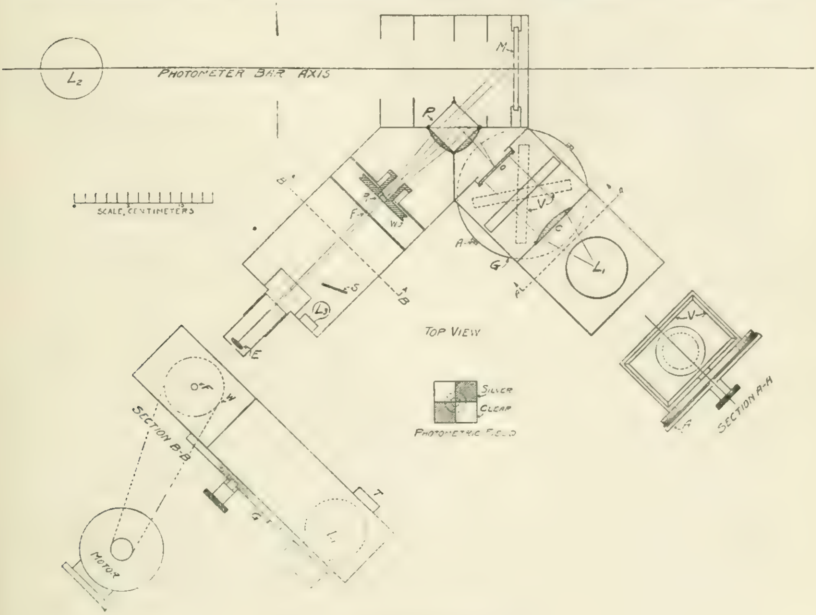

Fig. 3.—Flicker photometer.

V Variable neutral tint absorbing screen.
L_1 Comparison lamp.
P Photometric field.
P_1 Revolving prism.
M White test surface.
L_2 Test light.
F White external field.

observers measured this and in selecting a smaller number for practical routine work they are always selected so that the mean value of their readings on the green solution corresponds to the mean value of all. As observers have been transferred or become unavailable from time to time other groups have been formed on this basis. We, therefore, have in our results the practical equivalent of measurements by twenty-five observers.

The actual work was carried out substantially as follows: A preliminary test determined the relative positions at which the test lamp should be placed in order to produce the same brightness of the photometric field, both with the clear water and with the solution. The first series of measurements was upon the solution used over the standard 4-watt color lamp. For this purpose a 100-cp. stereopticon carbon lamp, practically a point source, was utilized. It was carefully matched in color against a standard specially secured from the Bureau of Standards. The clear water and the solution were measured alternately, uniformly five settings of the one, then five of the other, then repeat until ten settings in all were obtained. The colored solution was immersed between each set in a water bath at 20 deg. C, to which temperature all quoted values refer. These measurements, carried out for each step of 4 per cent. in concentration, gave one branch of the curve—that for the use of the solution on the comparison lamp side.

The calibration for use on the test lamp side was more complicated. As the test lamp a special singe-loop type "C" tungsten lamp was used, kindly furnished by the General Electric Company research laboratory, at Schenectady. The first step was to determine the voltages at which the light from this lamp, passed through each chosen concentration of solution, matched the 4-watt color. This done the rest of the work was as before, except for the lamps being run at a different voltage with each solution concentration.

The general procedure was exactly as in ordinary precision photometry, so that it need not be described in detail. The only special correction was that applied to the distance, in order to compensate for the thickness of glass and water in the tank—a correction made by taking three quarters of the water thickness and two thirds of the glass distance, the refractive indices of water and glass being practically four thirds and three halves respectively.

RESULTS.

Transmission Curve.—The mean values obtained for the transmission of the yellow solution at 20 deg. C are exhibited in the large scale diagram Fig. 4. The method of plotting deserves a

word. On the right of the center line the values are those of the

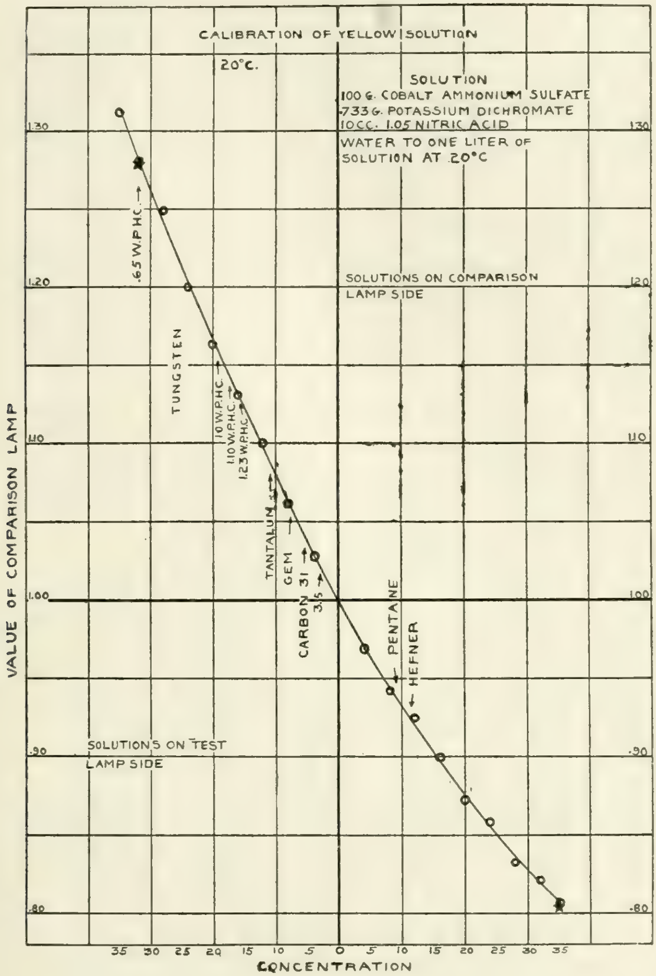

Fig. 4.—Calibration of yellow solution, 20° C.

Solution:

100 g. cobalt ammonium sulfate.

733 g. potassium dichromate.

10 cc. 10.5 nitric acid.

Water to one liter of solution at 20° C.

transmissions of the yellow solution (as compared with water) when placed over a 4-watt color lamp. They are then the

relative values to be ascribed to the comparison lamp in terms of its value as measured through the clear water against the standard. On the left of the center line are plotted, not transmissions, but the reciprocals of the transmissions. They thus become the relative values to be given to the comparison lamp in terms of its value as determined against the standard, the latter acting through the clear water. The whole curve, therefore, consistently gives relative values to be ascribed to the comparison lamp, the water tank and solution being used on the comparison lamp side, or on the test lamp side, as indicated. When the solution is used on the test lamp side, it must be remembered that the transmission value given holds only if the test lamp is at such an efficiency that the resultant light through the solution is of 4-watt color.

Precision and Range of Observation.—Two complete series of observations were made, one tank being used for the colored solution the first time, the other tank the second time. The precision of the results may be indicated by the mean values obtained on the two series for each concentration.

TABLE I.

Concentration per cent.	Comparison lamp side			Test lamp side		
	1st set	2nd set	Per cent. difference	1st set	2nd set	Per cent. difference
35	0.809	0.807	0.12	1.309	1.314	0.38
32	0.818	0.823	0.61	1.282	1.280	0.16
28	0.833	0.833	0.00	1.248	1.250	0.16
24	0.861	0.857	0.46	1.201	1.199	0.17
20	0.876	0.868	0.92	1.166	1.160	0.52
16	0.906	0.894	1.36	1.131	1.129	0.17
12	0.931	0.919	1.30	1.097	1.104	0.64
8	0.944	0.942	0.21	1.055	1.067	1.13
4	0.976	0.971	0.51	1.030	1.024	0.58

Average difference between two series 0.52

The fact, as explained above, that the corps of observers was somewhat changed, both in number and in personnel, between and during the making of the two sets as various conditions of the general laboratory work demanded, makes this table an index to the validity of our method of selecting observers, while not probably doing full justice to the precision of the photometric method.

The extreme variation between the individual observers in some cases is as much as 6 per cent., which indicates clearly the need for some such selection of observers from a large number as was here done. None of the observers used were far from the mean in their measurements constituting the preliminary selection. Had we merely selected seven observers at random from those available, we might easily (in fact probably) have used a group whose mean value would be two or three per cent. different from this group.

Temperature Coefficient.—It must be recorded as one of the disadvantages of absorbing solutions for photometric work that their transmission varies with the temperature. The plotted values were obtained for 20 deg. C (68 deg. Fahr.) and wherever possible work with this solution should be done at that tempera-

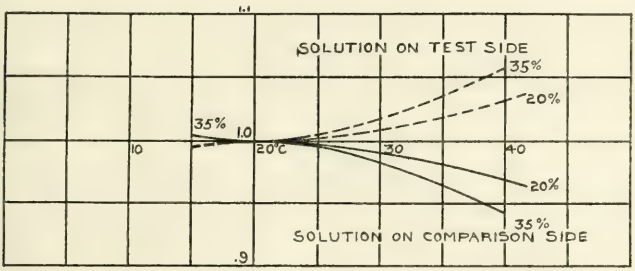

Fig. 5.—Temperature coefficient of transmission of yellow solution.

ture. In order, however, to make possible the use of the solution at other temperatures we have measured the change of transmission with different temperatures for two concentrations. From these figures, as plotted in Fig. 5, the transmissions for any working temperature may be obtained by interpolation.

DISCUSSION.

General Remarks on the Use of Absorbing Solutions.—It must be said that much of the apparent simplicity promised by the use of colored absorbing solutions is lost in actual practical trial. This is chiefly due to the extreme care which must be taken in the construction, selection and maintenance of the glass tanks. If the purely mechanical sources of error due to them could be entirely eliminated, we could speak with more enthusiasm of

the general scheme. Furthermore, the necessity of determining by trial and error the exact concentration called for is an inconvenience in some classes of work. This labor can be minimized by utilizing variations of thickness in making the determinations. Thus by means of a wedge cell, shown in Fig. 6, a close approximation to the correct concentration is obtainable, on the basis of Beer's law that concentration and thickness are equivalent. If some satisfactory cell, adjustable in thickness, could be devised, capable of easy cleaning and containing preferably not more than two glass faces, it should be advantageous to calibrate the solution by thickness and use it so. Our experience with

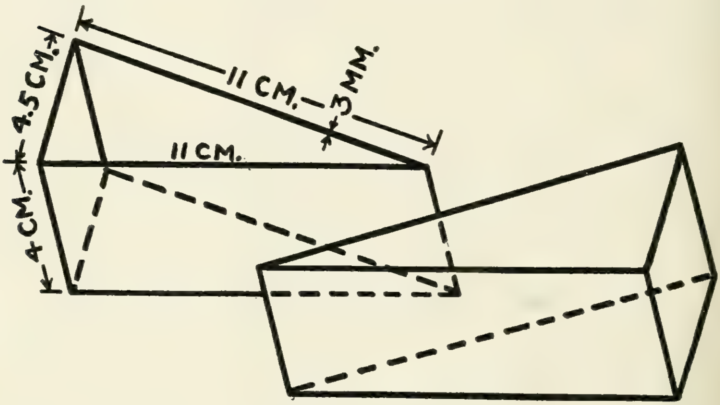

Fig. 6.—Wedge absorption cells.

errors introduced by the simplest form of tank discourages us at the present time from experiment with any adjustable tanks known to us. (We have actually constructed absorption vessels whose two faces, lying in the horizontal plane, are adjustable by screw motion. The convenience of such a method of color variation is most attractive, but the uncertainty introduced by evaporation and contamination bar its use). We feel it desirable to speak thus cautiously, because due to the perfection of the color match obtainable we think the danger to those who may use the solution is that they may forget that errors due to tank imperfection may be just as big obstacles to accurate results as was the color difference to be overcome by their use. The absorbing

solutions in these tanks call for just as much care as do any other parts of the precision photometer. However, when all precautions are taken it should be possible for all laboratories, furnished with the regular carbon lamp standards and a mutually accepted solution calibration curve, such as that here given, to measure incandescent lamps of any now attainable efficiency with uniform results. The actual possibility of achieving this long-desired uniformity is of sufficient importance to warrant some trouble in performing the measurements.

Remarks on Photometric Methods.—Occasion may be taken to say a word about the photometric method here used, which involves the use of the flicker photometer. These remarks must be chiefly by way of repetition of what has already been presented to the Society or has appeared in scientific periodicals, for although several papers have appeared on the subject of colored light photometry, arriving at various conclusions with respect to the flicker photometer, nothing has come to our attention which contradicts the experimental results printed in the original publication by one of the present writers. The conclusions drawn, therefore, are unaffected, especially those on which the photometric method here used is based.[4] In general it appears to us that too much attention has been focussed on the fact that the flicker photometer is used and too little on why it is recommended. The object sought is the determination of the relative luminous intensity of different colored radiations. The flicker photometer is recommended because when properly used it makes this determination possible without prohibitive labor.

Let us repeat here that there is no meaning to the expression 'relative intensity' applied to colored lights, unless the conditions of comparison are defined. The proposition of the senior writer was that the conditions to be chosen are those under which the flicker photometer and the equality photometer measure the same, as determined by extensive experiments, thus making possible the use of the convenient and reliable flicker photometer. Remember that some definite conditions must be specified if a practical definite value is to be ascribed to a colored light. Re-

[4] A paper on the theory of the flicker photometer, by the present writers, will shortly be published in the *Philosophical Magazine*, in which additional support is furnished to these conclusions.

member, too, that progress in artificial light is likely to be toward the higher illuminations of daylight, and additional reason is given for adopting as standard the brightness of 25 m-c +, corresponding to the small photometric field at 25 m-c.

In further elaboration of the statement that the flicker photometer should be looked upon simply as a means to an end, it may not be out of place to state that we expect shortly to describe several alternative means of light measurement. Among them will be entirely physical ones, in which the eye is used merely to

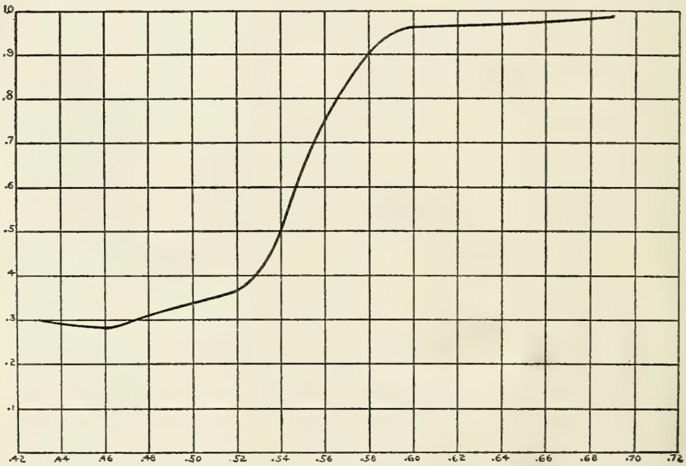

Fig. 7.—Spectral transmission of 35 per cent. yellow solution at 20° C.

read the position of a pointer. Such physical photometers have been proposed several times and experimentally developed. They have not, however, been available for practical use for two reasons. First, they have lacked sensibility, a defect which is rapidly being overcome with the advance of physical science and, second, there has been no established criterion of heterochromatic photometry to which the physical photometer readings should conform. The physical photometer must in short read as the average eye.

In connection with the efforts we are now making in this direction we have used our results on the yellow absorbing solution as a test of the self consistency of the photometric method.

Fig. 7 shows the transmission of the yellow solution as determined by the spectrophotometer.[5] We have combined these values with the luminosity curve of the average eye, as determined from 18 observers in Cleveland, and applied it (35 per cent. solution) to the black body at 2,080 deg. (4-watt lamp) and (32 per cent. solution) to the energy distribution curve of a 0.65 w. p. c. tungsten lamp (data from a paper by Coblentz). The calculated values from the ratios of the luminosity curve area with and without absorption, are shown by stars. They fall so close to the observed values that we feel justified in drawing two conclusions:

1. That the experimentally determined conformity of the flicker method to the arithmetical axioms discussed in the previous papers is again confirmed.

2. That the average eye as determined by the group of eighteen observers in Cleveland is substantially the same as that determined by another group of twenty-five in Philadelphia.

We may therefore conclude our discussion of the Fabry colored absorbing solutions by the general statement that the scheme when carefully carried out offers an attractive and practical means for securing uniformity in colored light photometry. We hope to make available other means to the same end, all however consistent with each other. We also hope to publish subsequently measurements on useful solutions other than the yellow one here described.

DISCUSSION.

MR. F. E. CADY: The solution of the problem of heterochromatic photometry through the use of colored absorbing solutions appears at first sight simple. The idea is old, as noted by the authors, but one of the great values of a paper of this kind is that it shows up clearly the difficulties encountered when an effort is made to utilize some of these older suggestions in modern, highly accurate work. Are not these difficulties which have been so clearly set forth another argument in favor of that suggestion which has been made a number of times, that the problem of color

[5] By plotting log. opacity against $\frac{1}{\lambda}$ it is found that this solution only roughly approximates the straight line theoretically desired.

photometry should be referred to a standard referee, such as the Bureau of Standards, which should be prepared to furnish either incandescent lamp standards calibrated for voltage, to give a match in color with anything from the Hefner up, or colored glasses whose transmission they would standardize? If, with so much care taken, and with experienced observers, differences were found as high as 6 per cent., as stated on the thirteenth page of the paper, it would seem like a rather hopeless task for the ordinary laboratory, either in the factory or the gas works, to utilize such solutions satisfactorily. This statement should not, however, be construed as an indictment against the use of such solutions in the laboratories where the facilities both in equipment and observers are adequate to insure that the proper precautions are being taken.

MR. T. H. AMRINE: I think anyone who has made merely a casual trial of this method of using colored solutions is apt to be over-enthusiastic about it, because one really does get a beautiful color match very easily. However if you go into it a little further, as Dr. Ives has noted, due to the difficulties encountered in the way of tanks and in getting permanent solutions, and reproducing solutions, and so on, the method is not so promising; but I am glad that somebody has had the courage to go on with it. I started out with this method in measuring the new high efficiency tungsten lamps but I ran into difficulties, and soon saw that it would take so long to accomplish what was wanted, that I dropped it and went to other methods.

DR. C. E. K. MEES: This paper seems to me to be a most fortunate complement to my paper.* This solution of Dr. Ives is a primary standard, where my filters were intended for secondary standards for the same kind of work, and while mine are meant for practical laboratory work under ordinary conditions, this is a reproducible standard method. I think the idea that this subject of heterochromatic photometry should be referred to any one laboratory is a mistake, because at present, probably, heterochromatic photometry is occupying the attention of every photometric laboratory in the whole world, and I think that by referring it to any one laboratory, or even to the international standardizing

* Mees, C. E. K., Light Filters For Use in Photometry; TRANS. I. E. S., vol. IX, No. 9.

laboratories throughout the world, we should merely be shifting a burden that all the laboratories are hardly able to bear onto a fewer number of workers. As a rule, it seems to me that investigation work should be transferred to the standardizing laboratories only when the earlier development work is completed, and when only an international institution has authority to fix the standard. That course was pursued in the case of the international electrical unit; the work of standardizing the international electrical unit was not performed by an international laboratory, but by Lord Kelvin and by observers throughout the world, and then it was transferred to the international standardizing laboratories for the values found to be legalized.

PRESENT PRACTISE IN THE USE OF TUNGSTEN FILAMENT LAMPS FOR THE LIGHTING OF METAL WORKING PLANTS.*

BY A. L. POWELL AND R. E. HARRINGTON.

Synopsis: This paper gives the results of an investigation of the lighting of various metal working plants. A discussion of the different methods of lighting commonly employed and the types of reflectors most generally applicable is followed by a consideration of the processes found between the ore and the finished product. The following data on the different operations is compiled: class of work, size of lamp, style of reflector, spacing of lamps, type of illumination, hanging height and watts per square foot. As this information is taken from plants that are satisfactorily lighted from the standpoint of the management and workmen, it should be of value as a guide to the designer and of considerable use to the practical engineer and commercial man.

INTRODUCTORY.

Within the last few years methods of lighting industrial plants, which are giving satisfactory service in a large number of cases, have become standardized to a considerable extent. But little data, however, has been presented before the Society relative to this particular phase of lighting. It seems desirable, as a matter of record, that an outline should be drawn up covering the progressive steps in metal manufacture and the systems generally applied for their illumination.

The authors make no special claim for originality, but have endeavored from their experience to describe, in as brief a manner as possible, the present state of the art.

Good lighting in industrial plants is an essential to satisfactory and efficient operation. The arguments in favor of better illumination for this particular class of service have appeared in the TRANSACTIONS in a number of excellent papers.[1] For instance,

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

[1] Flexner, M. H., and Dicker, A. O.; "Factory lighting," vol. VIII, 1913, p. 470.
Newman, Joseph Jr.; "Good lighting from a factory viewpoint," TRANSACTIONS I. E. S., vol. V, 1910, p. 874.
Simpson, R. E.; "Illumination as a safety factor in industrial plants," vol, IX, 1914, p. 459.
Stickney. G. H.; "Mill lighting" vol. VI, 1911, p. 478.

the necessity for well lighted stairs, passageways, etc., is very well covered in the third reference cited. A lengthy repetition of these facts is unnecessary, but they may be summarized as follows without analyzing the why and wherefore:

Correct Illumination:
- Reduces the number of accidents.
- Makes a more sanitary shop.
- Results in more agreeable and comfortable working conditions.
- Protects the eyes of the worker.
- Increases the amount of output.
- Improves the quality of production.
- Decreases the percentage of seconds.
- Reduces the cost of the lighting itself in many instances.

All these factors combine to raise the standard of the organization along humanitarian and economic lines.

METHODS OF LIGHTING.

In general we may classify lighting systems in two manners; first, as to the means of getting the light to the working plane or surface to be illuminated; and, second, as to the arrangement of units.

1. Three systems of lighting are generally recognized: direct, indirect and semi-indirect. The last two require ceilings clean and light in color, and since in the majority of metal working plants the ceiling is either dirty or broken by trusses and skylights, the first alone will be discussed in this paper. (The authors consider a direct lighting unit as one from which over half of the emitted light flux is directed downward or to the side, reaching the surface to be illuminated without being reflected by the walls or ceilings.)

2. The lighting units may be arranged in three fashions, furnishing what are frequently termed local, general and localized-general or group lighting. Naturally, combinations of these may be derived. General illumination supplemented by local lighting is often good practise and is much more frequently employed than any of the other combinations possible.

Local Lighting.—This system consists of the use of the smaller sizes of incandescent lamps placed close to the work and under

the control of the workman. Its use became prevalent because, first, the earlier types of incandescent lamps did not emit a sufficient flux of light to permit their being hung any great distance above the working plane; second, the efficiency of these earlier lamps was so low that from an operating standpoint it was impossible to obtain good illumination at any place but on the work. This system of illumination is inherently bad, for it produces a high intensity over but a small area, leaving the rest of the room in comparative darkness. Thus whenever a workman looks away from his work a certain time element is needed in order that his eyes may accommodate themselves to this great change in intensity. Very often the illumination on the work is far too great for the operation performed, which often results in ocular fatigue. In addition, when using this system the workmen lose time in adjusting their lamps and the breakage is increased by handling. It is true that there are certain processes where it is necessary to use a local lamp; for instance, when inspecting the interior of a mould or deep boring, or where extremely fine work is in progress, such as the manufacture of watch parts. In the last instance it would be inadvisable to light the entire room with the very high intensity required by the work. In cases where local lighting is essential it is advisable to provide a moderate value of general illumination to prevent a great contrast in intensity.

General Lighting.—In this system medium or high candle-power lamps are employed. They are to be spaced systematically with reference to the building construction, and such reflectors chosen as will produce approximately even illumination over the entire area. It has special application in large, open spaces where heavy work is done, such as rolling mills, forge shops, foundries, etc. Where closer work is carried on a modification of this system should be used, for it is desirable here to have the maximum intensity at the working points with lower values between machines.

Localized-General or Group Lighting.—This is the system referred to as a modification of general lighting. As its title implies, the lamps are located with respect to the work, medium size units being hung at moderate heights. The disadvantages

noted under local lighting are done away with and as satisfactory results are obtained as with general lighting, and not as much energy is necessary.

LAMPS.

Tungsten filament lamps are standard for 105 to 125 volts in steps from 10 to 1,000 watts, at efficiencies ranging from 1.30 to 0.55 w. p. h. cp. respectively. For multiple operation on circuits from 220 to 250 volts the standardized lamps range from 25 to 500 watts with efficiencies varying from 1.33 to 1.00 w. p. c. Due to the various efficiencies of incandescent lamps the values of average watts per square foot, given later in the text, have all been reduced to the basis of 1 w. p. c. or, approximately, 10 lumens per watt.

In average practise local lighting employs the smaller sizes, 10 to 40 watts; localized-general system utilizes from 60 to 150 watts and general illumination is supplied by lamps between 100 and 1,000 watts. Naturally, special cases produce deviations from this grouping.

REFLECTORS.

Reflecting devices may in general be divided into two groups —glass and metal. Glass reflectors may be very efficient and produce excellent illuminating results, and in the case of translucent types make a bright and cheerful shop. However, in industrial service the danger of breakage is an element which has prevented their adoption by the majority of plant managers. Another point, which often makes their use inadvisable, is the question of cleaning. Everyone realizes that periodical cleaning of lamp and reflector is extremely desirable and necessary if the system is to operate at its most efficient point. Nevertheless, in too high a number of cases this is neglected. In such instances an opaque metal reflector, if covered with a layer of dust on the outer surface, does not present as untidy an appearance as a dirty translucent reflector.

Since in practically all the plants investigated metal reflectors are used, the data presented is based on the use of this type. A previous paper before the Society[2] presented an excellent out-

[2] Rolph, T. W.; "Metal reflectors for industrial lighting," TRANSACTIONS I. E. S., vol. VIII, 1913, p. 268.

line of the metal reflectors available for industrial lighting. The authors' experience has indicated that a well made porcelain enamel finish is most generally applicable for this phase of lighting, on account of its ease of cleaning, resistance to acid fumes, heat and moisture, high initial efficiency and lack of permanent depreciation.

A great deal has been said of the deep bowl versus the shallow dome shape. From a standpoint of eye protection the deep bowl is to be preferred, but the investigation showed a far greater number of the dome shape in service. It is true that a large percentage of these may have been installed through clever salesmanship, or due to the fact that the lamp is visible and the exposed filament gives the layman the impression that he is getting more light. Yet, the shallow type has certain inherent advantages which indicate that in spite of the theoretical disadvantages it is the shape which is of most general service. These are as follows:

The downward flux of light for a given wattage is considerably greater than with a deep bowl reflector; more light is emitted at the obtuse angles, producing better illumination over vertical surfaces; light escapes near the horizontal, permitting use on quite wide spacings without dark spots midway between the units; and lastly, a brighter and more cheerful shop results. Of course, the hanging height must be such that the lamps are well above the angles of the vision and when this factor is taken care of the glaring effect is not severe, as the light emitted at high angles makes the walls bright and lessens the contrast between lighting unit and background.

MEANS OF SECURING DATA.

Typical well lighted metal working plants of the various kinds, as given later, were investigated either through a visit to the plant or the data obtained from plans showing layout of machinery and lighting equipment. In each case inquiry was made as to the degree of satisfaction given by the lighting. Those plants which are listed are well lighted and satisfactory to the management and employees, hence the data is of value as a guide for the designer. The following facts were obtained in each

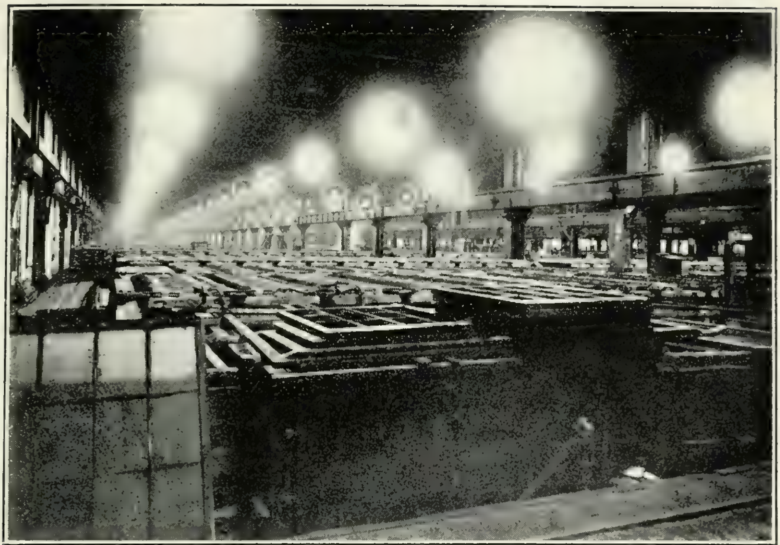

Fig. 1.—Night photograph Raritan Copper Works, Perth Amboy, N. J., showing general illumination of the electrolytic refining tank house.

Fig. 2.—Night photograph of foundry of A. & F. Brown Co., Elizabethport, N. J., showing general illumination applied to light bench and floor moulding.

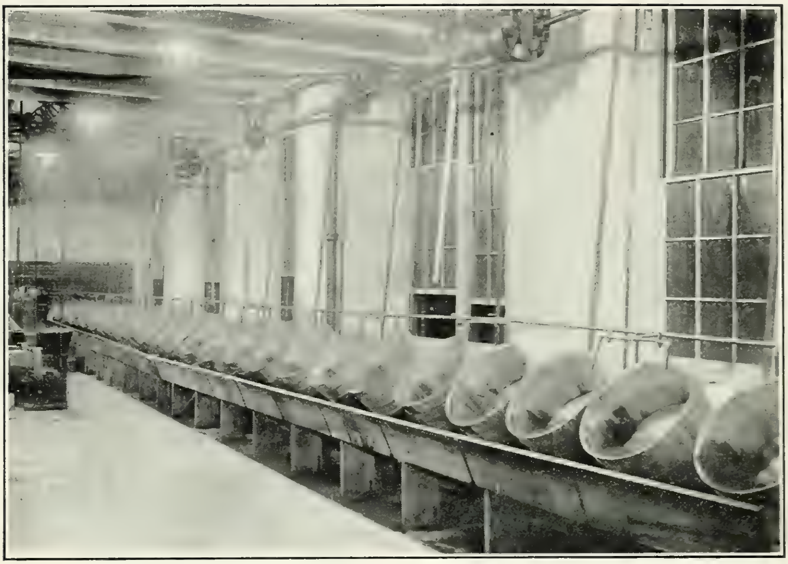

Fig. 3.—Night photograph of well illuminated tumbling barrels in a New England factory.

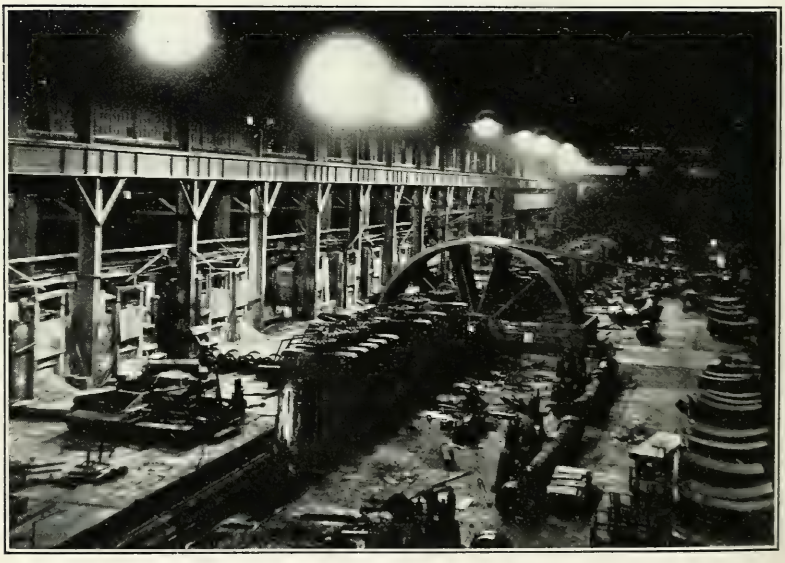

Fig. 4.—Night photograph of a large rolling mill at Follansbee, W. Va., well lighted by large units.

case: class of work; size of lamp; style of reflector; spacing of lamp; type of illumination; hanging height; watts per sq. ft.

For the use of the practical engineer and commercial man the value of energy per unit of floor area, based on successful installations, seems of more importance than the resultant illumination expressed in foot-candles. The technical man, if given the equipment, spacing, etc., can readily estimate the illumination from his knowledge of the utilization factors or the effective lumens per watt.

DIVISION OF METAL WORKING OPERATIONS.

Ore Working:
- Crushers
- Concentrators
- Racks, etc.

Extraction:
- Heat
  - Smelting or reducing furnaces
  - Blast furnaces
  - Puddling furnaces
  - Crucibles
  - Bessemer converters
  - Open hearth furnaces
- Electrolytic refining

Metal Working:
- CASTING
  - Moulding
    - Bench
    - Floor
    - Machine
  - Core making
  - Charging cupolas
  - Pouring
  - Tumbling
  - Cleaning, chipping and filling
- ROLLING
  - Shingling
  - Steam hammers
  - Rolling
    - Bars
    - Rails
    - Plates
    - Rods, etc.
- FORGING
  - Hand anvil
  - Machine, drop and press
  - Tempering and hardening
- CUTTING OR MACHINE TOOL WORK
  - Lathes
  - Planers
  - Shapers and slotters
  - Drilling and boring
  - Milling machines
  - Grinding
  - Saws
- BENCH WORK

Wire Working
- Cold drawing
- Weaving
- Twisting
- Finishing

Sheet Metal Working
- Punching
- Pressing
- Shearing
- Spinning
- Buffing

Assembly
Erection and Testing
Painting

ORE WORKING.

This heading includes such a wide variety of plants so radically different in construction that it is difficult to attempt a tabulation of data which would be of service. In general, the building is broken up by elevators, chutes, conveyors and the like, so that evenly distributed lighting is impractical. It is usually necessary to illuminate to a moderate intensity certain important parts of the system, such as racks, separators, concentrators, jigs, drying tables and loading platforms. In cases where crushing machinery, pumps, fans, motors, etc., are widely separated it is essential to locate the lamps with reference to these, so there will be plenty of light for adjustment and repairs. In other words, local lights are needed at various points, but these should be in the form of medium size lamps with reflectors giving a wide spread of light hung fairly high so that they will furnish some general illumination.

Passageways, stairs, ladders and hoists should all be adequately equipped as to lighting.

HEAT EXTRACTION OF METAL.

As with the ore plant, the reducing plant varies widely in arrangement of apparatus and construction of building; hence, the citation of specific cases is difficult and such discussion as can be given must be of a general order.

The molten metal itself and the fires, in a great many cases, provide plenty of light with which to carry on the operations. Nevertheless safety demands that artificial lighting be supplied. The installation is often required to supply more light when the

processes are not in active operation, or under emergency conditions, than for the regular operation under normal conditions.

Smelting and reducing furnaces for the rarer metals are usually small in size and a moderate intensity of general illumination should be supplied for the entire room.

The blast furnace house should have light enough for the workmen to repair the tuyer mechanism, to watch the water system from the ground and to readily discern tools lying about the floor.

In the puddling and open hearth plants the crane man must be able to see the workmen pick up ladles and cinder or slag parts. The movement of charging cars and cranes must be visible to the floor man and there must be enough light for them to break up and load slag.

The crucible house is usually adapted to a low intensity of general lighting from medium size lamps.

Bessemer converters and electric furnaces should be well illuminated by large lamps to facilitate charging and operation.

Electrolytic Refining.—Evenly distributed general illumination is desirable here as all parts of the room have the same requirements. A high intensity is not necessary as there are no moving parts to avoid, no close work is carried on and merely enough light is required that the operators may readily remove electrodes, clean out tanks and inspect electrical connections. In the larger tank houses the overhead space is without obstructions, although in some small and special cases hoods are provided to take off acid fumes. Porcelain enamel finish reflectors are essential for satisfactory service. The receptacle should be so protected as to prevent corrosive action.

TABLE I.—TANK HOUSE.

Plant	Work	Size lamp. Watts	Type reflector	Type Illumination	Average spacing. Feet	Hanging height Feet	Watts per sq. ft.
A[1]	Copper	150	Porc. dome	General	26 x 36	19	0.20
B	"	250	" "	"	25 x 25	20	0.45
C	"	40	" "	Loc. gen.	14 x 8	8	0.35
D	Nickel	150	" "	General	18 x 20	10	0.45
E	"	150	" "	"	20 x 20	12	0.40
F	"	150	" "	"	16 x 20	10	0.50

[1] A night photograph of this installation is given in Fig. 1.

CASTING.

Bench moulding and core making are usually carried on in a room separate from the pouring, or in a side bay. The methods of bench lighting, discussed later, apply here. Forty-watt lamps with reflectors giving intensive distribution on 8-ft. (2.44 m.) centers provide adequate illumination for small and medium work. Provision should be made for a portable lamp or a mirror with which to examine the interior of deep moulds. Where tables are scattered about the entire room general illumination serves very well.

TABLE II.—CORE ROOM.

Plant	Work	Size lamp. Watts	Type reflector	Type Illumination	Average spacing. Feet	Hanging height Feet	Watts per sq. ft.
A	Med. iron	100	Porc. dome	General	10 x 15	10	0.65
B	Large iron	60	" "	"	10 x 10	12	0.55

Machine moulding is ordinarily done in the main bay and the general illumination here will meet the requirements of this process; if in a separate part of the plant, present practise provides medium size units localized with reference to machine. The dome reflectors give sufficient spread of the light for adjoining spaces. Although no plants were examined where any one part was devoted exclusively to machine moulding, it is safe to estimate that from 0.3 to 0.8 watt per square foot would be required depending on the fineness of the work.

Floor moulding and pouring occupies a large open space which is adapted to general illumination. Two schemes are in common use for arranging lighting units. Large lamps with dome or bowl reflectors, symmetrically spaced above the crane travel, or medium size units with angle reflectors at the sides below the crane tracks. The second arrangement has, among other good features, an advantage that the crane does not have to be employed in replacing a burned-out lamp, and no shadows are cast by the crane. Naturally, the amount of light necessary will vary with the kind of output. Large iron castings require less illumination than small brass parts. Where a diversity of product occurs it is necessary to make provision for meeting the most difficult condition. This requirement of providing sufficient light for the safety of employees will always be taken care of if there is satisfactory light for the work.

Fig. 5.—Forge shop, Edison Lamp Works of General Electric Co., Harrison, N. J., showing general illumination with medium size lamps.

Fig. 6. -Bowl shape reflectors with medium size lamps used for general illumination in the machine shop of the Wheeler Condenser & Engineering Co., Carteret, N. J.

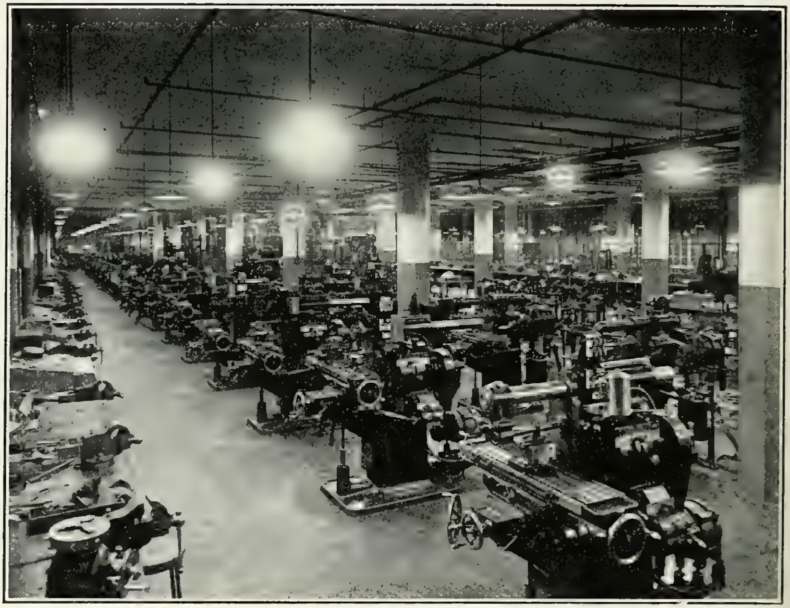

Fig. 7.—Night photograph showing localized-general illumination and bench illumination in the machine shop of the Edison Lamp Works of General Electric Co., Harrison, N. J.

Fig. 8.—Building 15, Pittsfield works of General Electric Co., lighted by large lamps in dome, angle and bowl reflectors.

Another feature, which must be borne in mind in designing the installation, is the deterioration. While initially the lighting used may give plenty of light for the work done, when the dirt, dust and moisture accumulate on the equipment between cleanings, the illumination may be reduced below the desirable value. Hence, it is always advisable in foundries to provide somewhat higher wattage than calculations on effective lumens indicate necessary.

TABLE III.—FOUNDRY.

Plant	Work	Size lamp. Watts	Type reflector	Type Illumination	Average spacing. Feet	Hanging height Feet	Watts per sq. ft.
A	Large iron	250	Porc. dome	General	22 x 16	20	0.80
B[1]	Small and med. iron	400	" "	"	21 x 21	22	1.00
C	Med. iron	150	" "	"	16 x 16	17	0.65
D	" "	400	" "	"	30 x 30	14	0.50
E	Small brass	250	" "	"	20 x 20	12	0.70
F	Small iron	100	" "	"	11 x 15	12	0.60

[1] A night photograph of this installation is given in Fig. 2.

Charging.—In most cases the general illumination of the main bay will be sufficiently spread to light the firing doors. In some plants, however, the cupolas are located on a mezzanine and in this event general illumination of a moderate value should be provided for safety.

TABLE IV.

Plant	Work	Size lamp. Watts	Type reflector	Type Illumination	Average spacing. Feet	Hanging height Feet	Watts per sq. ft.
A	Charging	150	Porc. bowl	Loc. gen.	18 ft. centers	15	0.50

The lighting of *tumbling barrels* does not demand a great deal of attention, for there is little danger of accident and close inspection is not essential. However, for small material and conditions such as shown in Fig. 3, localized-general illumination is often successfully installed.

TABLE V.

Plant	Work	Size lamp. Watts	Type reflector	Type Illumination	Average spacing. Feet	Hanging height Feet	Watts per sq. ft.
A	Very small brass	100	Porc. dome	Loc. gen.	12 x 12	11	0.70

Cleaning, rough chipping and filing of large pieces in most instances are done in the main bay after breaking up the flasks.

In some plants a separate section is allowed to this work which should have a low intensity of general illumination.

TABLE VI.

Plant	Work	Size lamp. Watts	Type reflector	Type Illumination	Average spacing. Feet	Hanging height Feet	Watts per sq. ft.
A	Med. iron	150	Porc. dome	General	16 x 16	15	0.65
B	" "	400	" "	"	35 x 35	14	0.35

ROLLING MILLS.

Although comparatively rough work is carried on and the processes are largely mechanical, say for adjusting rolls and other parts of the machines, yet the safety of employees demands that a moderate intensity of evenly distributed general illumination be supplied. Hot metal is twisting back and forth over the floor, rolls are lying about over which one might stumble, pits and troughs abound, all of which offer opportunity for accident unless clearly visible. The high, clear overhead enables the larger sizes of lamps to be used on symmetrical spacing.

TABLE VII.

Plant	Work	Size lamp. Watts	Type reflector	Type Illumination	Average spacing. Feet	Hanging height Feet	Watts per sq. ft.
A[1]	Structural forms	Cluster 4–250	Porc. dome	General	33 x 60	28	0.55
B	Bars, etc.	400	" "	"	34 x 42	32	0.30
C	Small rods	400	" "	"	28 x 28	20	0.55
D	Rails	400	" "	"	37 x 37	22	0.35
E	Plates	250	" "	"	38 x 38	35	0.20
F	Rails	1,000	Porc. bowl	"	40 x 40	40	1.15[2]
G	Rails	1,000	Porc. angle	"	40 x 20	32	2.2[2]

[1] A night photograph of this installation is given in Fig. 4.

[2] Actual watts per sq. ft. "F" and "G" are 0.6 and 1.2 respectively, the specific consumption of the lamps being 0.55 w.p.c.

FORGING.

A localized-general system of illumination is suitable for ordinary anvil or hand forging work. Although but a moderate intensity is required no dependence can be put on reflection from walls, and considerable dust is present, making the wattage somewhat higher than ordinarily necessary for a given illumination. Frequent cleaning of lighting equipment is essential. Tool forging, being of a finer order, demands somewhat more illumination than ordinary work.

TABLE VIII.—HAND FORGING.

Plant	Work	Size lamp Watts	Type reflector	Type Illumination	Average spacing. Feet	Hanging height Feet	Watts per sq. ft.
A[1]	Small machine parts	60	Porc. dome	General	10 x 10	11	0.55
B	Elevator parts	150	" "	"	16 x 20	15	0.50
C	Miscellaneous iron	250	" "	"	22 x 22	18	0.60
D	Engineering parts	150	" "	Localized general	19 x 19	13	0.45

[1] A night photograph of this installation is given in Fig. 5.

With drop and press machine forging particular attention must be paid to the arrangement of lamps as the overhanging parts may cast objectionable shadows. The amount of light as usual will depend on the size of work underway.

TABLE IX.—MACHINE FORGING.

Plant	Work	Size lamp. Watts	Type reflector	Type Illumination	Average spacing. Feet	Hanging height Feet	Watts per sq. ft.
A	Miscellaneous heavy	250	Porc. dome	Localized general	20 x 20	14	0.70

Hardening and tempering is often satisfactorily lighted by lamps suspended over the tanks with dome reflectors to spread the light sufficiently to illuminate the furnaces. This gives the high intensity required for examining the color before plunging and economically illuminates the entire room.

TABLE X.

Plant	Work	Size lamp. Watts	Type reflector	Type Illumination	Average spacing. Feet	Hanging height Feet	Watts per sq. ft.
A	Case hardening	100	Porc. dome	Localized general	10 x 10	10	1.00

CUTTING OR MACHINE TOOL WORK.

Up to within a few years plant managers have considered that the only proper way to light machines was by the use of small drop lamps located close to and directly above the tool. The introduction of the medium and high candle-power incandescent lamps and the gradual adoption of individual motor drive, rather than overhead belting and shafting, opened the way for considerable investigation into the lighting of various machines. This experimentation led to the conclusion that overhead lighting, when properly designed, was extremely satisfactory. Three

general arrangements of lamps have been adopted, as discussed in previous paragraphs.

Machine shops may be divided into two general groups depending on the class of work done; those devoted to medium, small or fine work an the other to coarse or heavy work. Even with this classification it is obvious that various amounts of light are demanded depending on the fineness of the work. Where work must be calipered or gaged down to the thousandth of an inch, more light will be desirable than where approximate sizing is sufficiently close. The three types of reflectors described above, namely, dome, bowl and angle, are all applied to this class of lighting. For instance, in Fig. 6 is shown bowl reflectors used for general illumination in a shop where medium work is done; in Fig. 7, dome reflectors are arranged to furnish localized-general illumination, fine work being carried on; all three types are used to furnish general illumination in the shop shown in Fig. 8, where medium and fine work is done, angle reflectors at the sides, bowl shape above the crane and dome shape between the bays below the crane tracks; localized-general illumination has been found to serve very well however. What is meant by this term localized-general illumination is illustrated in Fig. 9, where grinders are lighted by medium size lamps hung out of reach of the workman, the light from these lamps illuminating the surrounding spaces. If the machines are uniformly spaced and very close together, a system of general lighting may be equally applicable.

In arranging the lamps for localized-general illumination certain precautions should be taken; for instance, lathes should preferably be lighted from above and to the right of the chuck, so arranged that the workman does not cast a shadow. For millers and shapers the light should come from the front of the machine. Lamps should be arranged with reference to the position of planers, drills and the like, so that shadows are not produced by the machine head. A little experience or experimentation soon shows one the proper location of lamps for the different types of machines. In general, it is advisable to supply plenty of light for all work, although sometimes where cost would be prohibitive of a high intensity throughout, it may be

necessary to provide local lamps for setting up automatic lathes, millers and shapers or for doing fine planing.

TABLE XI.—GENERAL MACHINE SHOPS.

Small and Medium Work.

Plant	Work	Size lamp. Watts	Type reflector	Type Illumination	Average spacing. Feet	Hanging height Feet	Watts per sq. ft.
A	Screw machs.	250	Porc. dome	General staggered	16 x 16	12	1.10
B	Springs	100	" "	Loc. gen.	8 x 12	9	1.00
C	Gen. mach.	100	" "	" "	11 x 9	9	1.00
D	Auto. screw	100	" "	" "	10 x 10	9	1.00
E	Motor repair	100	" "	" "	7 x 14	9	1.00
F	Pipe	150	Porc. dome	General	—	10	0.3
	threading,	40	Enam. bowl	Loc. gen.	—	10	—
	etc.	60	" "	" "	—	10	—
G	Engine pts.	150	Porc. dome	General	16 x 11	10	0.95
H	Elevator pts.	100	" "	"	10 x 10	9	1.00
I[1]	Med. mach.	100	Enam. bowl	"	11 x 11	10	0.80
J	Med. mach.	60	" "	Loc. gen.	Varied	9	0.4
K[2]	Fine tool	100	Porc. dome	" "	12 x 8	9	1.00
L	Mach. repair	60	" "	General	7 x 8	11	1.00
M	Light mach.	250	" "	"	15 x 15	18	1.25
N	Light mach.	250	" "	"	14 x 17	22	1.15
O	Mach. repair	250	" "	General	Varied	14	0.5
		60	" "	Loc. gen.	"	8	—
P	Med.mach.	250	" "	"	12 x 24	11	0.95
Q[3]	General	500	Enam. angle	General	30 centrs	20	1.25
	manufac-		" bowl	"	15 x 30	32	1.25
	turing		" dome	"	30 centrs	20	1.25
R	Small pts.	60	Enam. bowl	"	8 x 8	9	0.90
S	Small engine pts.	150	Porc. dome	"	14 x 14	11	0.85
T	Med. mach.	250	" "	"	14 x 14	23	1.40

[1] A night photograph of this installation is given in Fig. 6.
[2] A night photograph of this installation is given in Fig. 7.
[3] A night photograph of this installation is given in Fig. 8.

The second class of work, namely, rough or coarse, is satisfactorily carried on with general illumination from medium and high candle-power lamps.

A study of the following data will show the present tendency in the lighting of machine shops:

TABLE XII—GENERAL MACHINE SHOPS.

Heavy Work.

Plant	Work	Size lamp. Watts	Type reflector	Type Illumination	Average spacing. Feet	Hanging height Feet	Watts per sq. ft.
A	Platform scales	60	Porc. dome	Loc. gen.	9 x 9	11	0.70
B	Structural parts	250	" "	General	17 x 17	12	0.95
C	Gas engines	500	" "	"	36 x 32	18	0.50
D	Heavy machine parts	250	" "	"	22 x 22	13	0.55
E	Heavy castings	400	" "	"	30 x 32	15 & 25	0.45
F	Electrical parts	400	Enam. bowl	"	17 x 18	23	1.45
G	Planing mill	250	Porc. dome	"	20 x 20	18	0.70
H	Locomotive parts	400	" "	"	35 x 35	13	0.35
I	Varied products	250	" "	"	12 x 20	13	1.15

BENCH WORK.

This classification covers a very wide variety of processes from rough filing, chipping and assembling down to fine engraving, small machine work, gauging and inspecting. Fortunately the requirements are similar and the principal variation is in the intensity of illumination needed.

Single benches may be located along the wall or in the center of the room; double benches are usually systematically spaced in the room with operators on both sides. The bench is usually 3 to 3½ feet (0.9 to 1.06 m.) in height; single benches varying in width from 2 to 3 feet (0.6 to 0.9 m.) and the double benches from 4 to 6 feet (1.2 to 1.82 m.).

Rough work on benches, regardless of what type, may be lighted by general illumination, but due to the liability of shadows, localized-general illumination is, therefore, most generally applicable for bench lighting. With the proper arrangement of units shadows are eliminated, and a variation in the size of lamp specialized will meet the intensity requirements.

The height of 5 feet (1.52 m.) above the bench will meet most conditions.

The single bench arrangement, as shown at the left of Fig. 7, is very satisfactory. The system employs lamps spaced on 6 to 10 feet (1.82 to 3.04 m.) centers in the 40 to 100-watt sizes with intensive type bowl reflectors. The row of lamps should usually be located about 6 inches (15.2 cm.) in from the front of the bench.

Double benches used for ordinary work can be well lighted by a row of intensive units down the center line of the bench. Double benches for fine work should have two rows of lamps arranged similarly to the recommendation for single benches.

Where vises are permanently attached it is desirable to locate the lights between two workmen, as there is less liability of shadow and more illumination on vertical surfaces.

TABLE XIII.

Plant	Work	Size lamp. Watts	Type reflector	Type Illumination	Average spacing. Feet	Height above bench, ft.	Watts per sq. ft.
A[1]	Fine and med. iron	60	Enamel extensive	—	8 ft. centers	5	—
B	Small iron	60	Aluminum intensive	—	8 ft. centers	5	—
C	Med. brass	40	Aluminum intensive	—	6 ft. centers	5	—
D	Med. iron	40	Aluminum intensive	—	6 ft. centers	4	—
E	Med. brass	40	Aluminum intensive	—	9 ft. centers	4	—
F	Fine jewelry	25	Aluminum focusing	—	3 ft. centers	2	—
G	Bearing inspection	100	Enamel intensive	—	10 ft. centers	5	—

[1] A night photograph of this installation is shown in Fig. 7.

WIRE WORKING.

The lighting requirements in a majority of the processes found in wire working are not very severe. Localized-general illumination of a medium intensity will be found to be quite satisfactory. In cold wire drawing sufficient light should be provided so that operators may perceive the moving wire, loose pieces of wire about the floor and the reels. As the operation of drawing is

done on a bench this is the place where the best light should be provided. After the operation is once started the work becomes entirely mechanical, although the operator must occasionally see that the wire is running to gage and that there are no flaws.

TABLE XIV.—COLD WIRE DRAWING.

Plant	Work	Size lamp. Watts	Type reflector	Type Illumination	Average spacing. Feet	Hanging height Feet	Watts per sq. ft.
A[1]	Drawing	250	Porc. dome	Loc. gen.	28 x 36	12	0.30

In *weaving and twisting*, if the machines are uniformly spaced, a system of general illumination will meet the requirements. The intensity should be medium with a higher value for the finer wire. If the machines are not uniformly spaced and are far apart a system of localized-general illumination should be used.

TABLE XV.

Plant	Work	Size lamp. Watts	Type reflector	Type Illumination	Average spacing. Feet	Hanging height Feet	Watts per sq. ft.
A	Wire weaving	150	Porc. dome	General	15 x 15	12	0.75

Finishing processes such as tempering, galvanizing, tinning, etc., may be lighted to good advantage by a system of general illumination. The intensity need not be high as the work carried on is not very close. For such processes as braiding and wire fence making localized-general lighting is more applicable. The units should be so located that the light will reach the machine in such a manner as to enable the operator to follow the work readily.

SHEET METAL WORKING.

Punching, pressing and stamping machines, unless equipped with safety devices, are quite dangerous to operate, and the protection of employees demands that these be well lighted. The actual operation is largely mechanical after the machine is set up, but the moving parts must be clearly visible. Lamps must usually be arranged so that the light comes from the front of the machine, and from the right or left of the operator to avoid shadows from the machine head and workman's body. In some cases large punch presses are advantageously lighted by general or localized-general illumination supplemented by localized lamps

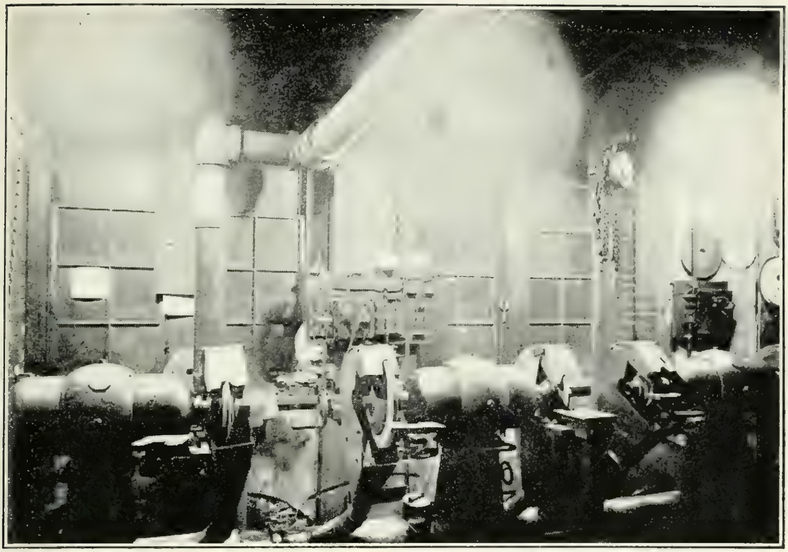

Fig. 9.—Night view illustrating the application of localized-general illumination above grinding machines.

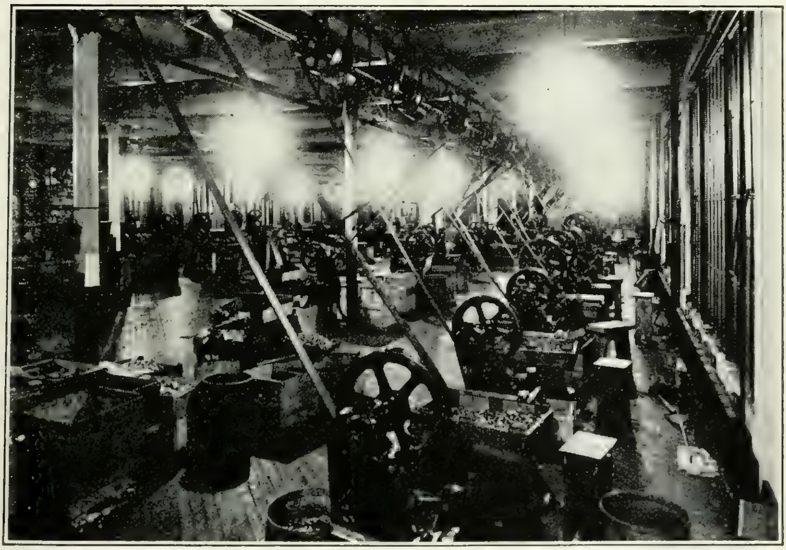

Fig. 10.—Localized-general illumination applied to medium size power presses at the Passaic Metalware Co., Passaic, N. J.

Fig. 11.—Night photograph of the erecting shop of the Gurney Elevator Co., Honesdale, Pa., lighted by 400-watt lamps in flat dome reflectors.

Fig. 12.—Paint shop, Public Service Railway, Newark, N. J., lighted by general illumination, using bowl and angle reflectors.

at the rear, the lamp itself being concealed from view by the machine.

Localized-general illumination with medium size units, or general illumination supplemented by local lights, are two alternatives. The local lamp should preferably be equipped with angle reflector arranged to direct the light as indicated.

TABLE XVI.

Plant	Work	Size lamp. Watts	Type reflector	Type Illumination	Average spacing. Feet	Hanging height Feet	Watts per sq. ft.
A	Heavy power press	150	Porc. dome	Loc. gen.	8 x 20	10	1.05
B	Small foot and power press	250	" "	General	17 x 17	10	0.95
C[1]	Medium power press	250	" "	Loc. gen.	20 ft. centers	11	0.65
D	Heavy structural punching	500	" "	General	37 x 37	33	0.35

[1] A night photograph of this installation is given in Fig. 10.

Cutting and shearing can be satisfactorily lighted with general or localized-general illumination of medium intensity, provided lamps and machines are so spaced that the predominating direction of light is toward the front of the machine.

Spinning and buffing are similar as to lighting requirements and present practise indicates that a localized-general system is well suited, although a slightly different arrangement of lamps is desirable. The spinning lathe should be illuminated from the front and right, whereas, a light directly above the front of the buffer will give the maximum intensity on the piece being polished.

TABLE XVII.

Plant	Work	Size lamp. Watts	Type reflector	Type Illumination	Average spacing. Feet	Hanging height Feet	Watts per sq. ft.
A	Brass pipe	60	Aluminum bowl	Loc. gen.	10 x 18	8	0.30
B	Fixture pts.	150	Porc. dome	General	12 x 13	10	1.05

ERECTING, ASSEMBLING AND TESTING.

Since the work is likely to be placed at any point on the floor, evenly distributed general illumination seems most desirable.

The intensity of light will, of course, depend on the class of goods being manufactured. There are three general methods of arranging the lamps and, naturally, combinations of these may be found, the height and spacing is often determined by the character of machinery being manufactured.

1. Medium or large lamps with bowl or dome reflectors placed close to the ceiling above the crane travel, as depicted in Fig. 14.

2. Medium lamps with angle reflectors placed at the sides of the bays below the crane tracks.

3. Medium or large lamps with dome reflectors placed below the crane tracks, when two or more bays are to be lighted.

TABLE XVIII.

Plant	Work	Size lamp. Watts	Type reflector	Type Illumination	Average spacing. Feet	Hanging height Feet	Watts per sq. ft.
A[1]	Elevators	400	Porc. dome	General	15 x 15	20	1.2
B	Condensers	250	" "	"	12 x 18	21	1.3
C	Metal sashes	150	" "	"	16 x 16	10	0.65
D	Locomotive pts.	400	Paint "	"	28 x 28	13	0.55
E	Structural steel	250 150	Porc. dome " "	" "	25 x 25 20 x 20	18 18	0.45 0.40
F	Platform scales	250	Porc. angle	"	20 x 20	16	0.70
G	Street car	150	Porc. dome	"	22 x 22	18	0.35
H	Gas engines	500	" "	"	12 x 40	15	1.15
I	Heavy met. She.	150	" "	"	15 x 15	18	0.75

[1] A night photograph of this installation is given in Fig. 11.

PAINT SHOP.

These usually have a clear overhead space and are well adapted to general illumination. A unit giving a fair percentage of light at obtuse angles is desirable for the illumination of vertical surfaces. As a great deal of the work is with black paint, a medium intensity is desirable to properly inspect the product. When lighting tanks, cars and other high objects, special attention should be given to the location of lamps, avoiding objectionable shadows.

TABLE XIX.

Plant	Work	Size lamp. Watts	Type reflector	Type Illumination	Average spacing. Feet	Hanging height Feet	Watts per sq. ft.
A[1]	Cars	150	Alum. angle Alum. bowl	General	15 x 18	13	0.6
B	General product	250	Porc. dome	"	18 x 18	23	0.85
C	Tanks	500	" "	"	16 x 34 staggered	31	1.00

[1] A night photograph of this installation is given in Fig. 12.

CONCLUSION.

While it will be noted that there are many classes of metal manufactory, where the character of buildings and other local conditions are so varied as to prohibit any useful standardization of the lighting, the practise in general can be greatly improved by the classification and dissemination of information concerning what is being done in representative plants. It is hoped that further extension of the work along the lines suggested in this paper will be helpful in bringing about the adoption of methods, which will not only increase the efficiency and effectiveness of manufactories, but also better the conditions as regards the safety, vision and health of operators. Such improvements will benefit not only the employers and workmen, but also the country at large, to whom individual workers are often changed from assets to liabilities through injuries received in their daily work.

The authors feel that a word of appreciation is due Mr. G. H. Stickney for his co-operation and suggestions during the preparation of this paper, and to Mr. E. F. Carrington for his kindness in securing a majority of the photographs used as illustrations.

DISCUSSION.

MR. R. B. ELY: We are indebted to the authors for photographs of some of the best lighted shops in the country. It is good missionary work to send illustrations of these shops broadcast. It is a splendid thing for this Society and for every lighting man. The figures of the actual energy consumption required for the lighting of these particular shops should be helpful to all those who have to consider similiar industrial lighting problems.

To try to install general illumination systems in our present foundries and machine shops to answer all purposes is uphill work at this time, on account of the initial cost as compared with the cost of installations now in use in many shops.

The authors state that the lighting of industrial plants which is giving satisfactory service in a large number of cases has become standardized to a considerable extent. My question on this point is who is putting the seal of approval on this standard method; and does this statement apply to a particular machine shop or a particular foundry?

There is a need of such standardization. From the commercial viewpoint, if there were some standard methods for illuminating shops many of the usual problems would be greatly simplified.

In considering the present wattage per square foot of the installations as they are to-day, I would say that in the average metal working shop the illumination does not exceed one-half watt per square foot under present conditions with old type lamps, that is, gem lamps. The lighting is bad, without doubt, and can be improved without considerable expense to the manufacturers, or the owners of such establishments, by simply substituting a lamp or by changing the entire system. To go the limit to give a complete general system of illumination would be a fine thing to do, but I do not think it can be considered as a standard or standardized practise.

I also want to speak about the tendency toward glass reflectors in the lighting of industrial plants, particularly such plants where female help is employed. When the deep bowl reflectors were first introduced they were used rather extensively due to the fact that they were recommended more strongly because they concealed the filament of the lamp from the eyes. These reflectors tended to darken the ceiling and give a gloomy appearance to the room as compared with an installation of the shallow bowl type. In some of the buildings of concrete construction where there are high ceilings and walls in fairly good condition there is a demand for illumination that will make it easy to see the ceilings and walls; so that a certain amount of general illumination must be furnished through translucent reflectors.

Mr. J. L. Minick: I would like to know if the author can give me any information concerning the use of the larger sizes of gas-filled lamps, 750 and 1,000 watts?

A problem I have in mind, which has been giving us some trouble, is that of an erecting shop used for building and repairing locomotives. A shop of this kind is generally from 50 to 60 feet wide and possibly several hundred feet long. A single track runs down the center with a track on each side close to the wall. The side tracks are not connected to the center track and locomotives are lifted from the center track by cranes and placed at the proper points on the side tracks. The space between the locomotive and side wall is quite restricted. On account of the use of the crane for lifting locomotives, all lighting must be placed above the crane. Lighting cannot be provided from the side walls below the crane. The minimum height from the floor to the lamp will run probably 60 feet and may go as high as 75 or 80 feet. I would like to know what the author would recommend, in the line of large size gas-filled lamps, to meet a condition of this kind.

Mr. H. T. Spaulding: A paper of this nature, containing tabuated descriptive data is always of great interest for checking and comparing information relative to size lamps, spacing, and resulting intensity.

It seems to me that the question of desirable intensity for industrial plants has not been given sufficient attention. In the past few years, the standard for this class of service has been raised considerably, and no doubt, this increase has brought about a higher efficiency of operation, and an increased production. Would not a further raising of the standard of illumination bring about a further saving? The cost of light is in every case so low, compared with the cost of labor, that if an increase in the illumination will increase the output of the plant by only a very few per cent., the additional cost will be well worth while.

Various tables of desirable intensities for different operations have been published from time to time, and as a rule they check fairly closely, but it is doubtful in my mind if sufficient thought and study have been given to their compilation. It would be possible to conduct a series of tests, at least in certain kinds of

plants, to determine the relation of illumination to efficiency of operation, and such data would surely be of interest, not only to illuminating engineers, but to the managers of industrial plants.

MR. C. A. LITTLEFIELD: The paper by Messrs. Powell and Harrington suggests a benefit to the central station by co-operation between the lighting and the power experts. I wish to speak merely as a representative of a central station company and will not undertake a technical discussion of this very interesting and valuable paper. Question may arise as to difficulties with, or cost of, adequately lighting a factory and a lighting expert may be called in to remedy the difficulties or suggest improvements. While going over the installation, a little observation on the part of the lighting expert may reveal considerable factory waste resulting from improper or poor power application. This would offer an excellent opportunity for the power expert to be brought into consultation and enable him to suggest remedies that would result in improved factory operation. To improve the lighting installation and effect a saving in this branch, but to suggest no improvements in a larger element of operating costs by overlooking any improper power application, does not carry with it harmony of action on the part of the central station or other experts.

Aside entirely from the philanthropic and economical standpoint, it is absolutely necessary, in order to comply with recent enactments of state legislatures upon the subject of workmen's compensation, to more adequately protect the operatives; and the subject of improved lighting conditions carries with it the importance, as well, of improved power application. It is for these reasons that the paper appeals to me as offering an excellent opportunity for co-operation on the part of the lighting with the power expert, as well as the power with the lighting expert.

MR. R. E. SIMPSON: As a representative of The Travelers Insurance Company, and therefore very much interested in the prevention of accidents, my attention is attracted by the last paragraph on the ninth page:

> The molten metal itself and the fires, in a great many cases, provide plenty of light with which to carry on the operations. Nevertheless, safety demands that artificial lighting be supplied. The installation is often required to supply more light where the processes are not in active operation, or under emergency conditions, than for the regular operation under normal conditions.

There is no doubt that the molten metal and the fires do provide in many cases an ample amount of light, but the chief difficulty is that the light is often of too high intensity, comes from the wrong direction, and is not very well distributed. The workmen, whether handling the metal in hand ladles, or in troughs, are obliged to look directly at the metal, thus reducing the pupils of the eyes to the size of a pin head. Naturally, their ability to see is greatly reduced because of the sharp contrast between the molten metal and the dark floor. The danger of stumbling over obstructions in the passageways is very great. It would seem then, contrary to the opinion expressed by the authors in the paper, that more light should be provided during the handling of molten metal than at other times, for the purpose of reducing to as large an extent as possible sharp contrast.

The report on the Conditions of Employment in the Iron and Steel Industry in the United States for the years 1905 to 1910, inclusive, shows that 40 per cent. of all accidents occur in the daytime and 60 per cent. during the night. The figures are taken on a basis of 300 working days per year and the number of accidents per 1,000 employed. The greatest discrepancy is in the yards, where there is generally a marked difference in the daylight and artificial lighting conditions. The figures here are 30 per cent. of the accidents occur during the day, and 70 per cent. during the night. The figures for the mechanical departments show 31 per cent. as the day rate, and 69 per cent. as the night rate. These figures tend to corroborate the oft-repeated statement that 25 per cent. of the avoidable accidents in this country may be attributed to the lack of adequate lighting facilities.

In the conclusion, Messrs. Powell and Harrington have struck the keynote as to the value of the paper. It is the dissemination of the practical and detailed information that has proved successful in a few plants that will gradually lead to better lighted shops in which both employer and employee are benefitted.

Mr. A. L. Powell (In reply): The question was raised as to the application of the high efficiency of tungsten filament lamps for the illumination of industrial plants. Everyone realizes that this is a comparatively new product and while there are a great many industrial installations under way these have not been in

service for a long enough time to warrant the incorporation of data regarding these particular installations in the paper. I believe, however, they would be very useful for the type installation Mr. Minick describes. The detail of the layout would take a little time, but if a combination of angle and bowl-shaped enameled reflectors with the large size lamps were used the problem could be readily solved.

Mr. Ely mentioned the uphill work necessary to install good industrial lighting. I believe that Mr. Littlefield in his discussion of the co-operation between the various branches of the service has practically answered this question. Our experience has been that progressive plant superintendents and managers are anxious to get the best possible conditions for their employees. This naturally includes adequate and proper lighting.

As to the installation of a localized system rather than a general illumination system, a very little calculation will show that the cost of installation and of up-keep of the former system is undoubtedly greater than for the latter. The expenditure for good illumination is such a small factor in the running expenses of the plant that there seems to be no excuse for a poorly lighted mill or shop.

Some question was raised in reference to the statement that the lighting of many processes were standardized to a certain extent. The National Electric Light Association and the bulletins of the various manufacturers of lighting accessories give much data along this line.

There are many instances where a compromise must be made and where absolutely the best installation is not used; nevertheless, I feel that as a result of this work the conditions are much improved.

ARTIFICIAL DAYLIGHT—ITS PRODUCTION AND USE.

BY M. LUCKIESH AND F. E. CADY.

Synopsis: The paper first deals with the general problem of producing artificial daylight. The color values of the old and new tungsten lamps are given and these illuminants are compared spectrophotometrically with two phases of daylight, namely blue skylight and clear noon sunlight. Ideal color screens for producing these two phases of daylight from the vacuum and gas-filled tungsten lamps have been computed. From these the daylight efficiencies of the lamps have been obtained. The theory and practise of the additive and subtractive methods of producing artificial daylight are described. The method of developing a color-screen for producing daylight for use with tungsten lamps is presented and this is accompanied with the practical results that have been obtained. A general discussion of other means of imitating daylight and a bibliography of the subject are given.

INTRODUCTION.

It has long been known that artificial illuminants differ in spectral character and that they are in general very different from daylight in this respect. However, the importance of the spectral character or quality of an illuminant is not generally recognized, although this is strikingly exemplified by the appearance of colored objects when illuminated by the various illuminants. Modern artificial illuminants having continuous spectra while differing considerably from each other are all in the same class when compared with daylight with the exception of the Moore carbon dioxide tube which is a close approximation to average daylight. This illuminant does not have a strictly continuous spectrum. However, for practical purposes it is a very satisfactory substitute for daylight, although its low efficiency prevents its adoption for the purpose of general lighting.

Daylight has become the accepted illuminant for many purposes. Therefore there is a need for artificial daylight in order that certain activities may be continued after nightfall or in places where daylight cannot be obtained in sufficient quantity. The trend in the development of illuminants has been toward

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

daylight quality, but notwithstanding the great progress made in recent years there is yet no artificial illuminant approximating daylight in color value that can be used for the purpose of general lighting. Without such an illuminant a natural step is to alter an illuminant having a continuous spectrum by means of colored screens so that the resultant light approximates daylight sufficiently closely for the intended purpose. Another obvious procedure is to add two or more illuminants of such character as to give a resultant daylight. Both possibilities have been known for many years. As early as the year 1900 Dufton and Gardner made and described a colored glass for use with an arc lamp which gave a resultant light approximating daylight closely enough to be adopted in the textile mills of England. The unit is still in use, although it appears to have been improved somewhat. In recent years several units, more or less satisfactory, have been developed.

In imitating daylight quality it is necessary first to determine just what kind of daylight is suitable for the purpose in mind. Daylight varies tremendously with time and place. Sunlight undergoes many changes throughout the day from the white of noonday sun to the reddish sunset. On the other hand, blue skylight is very different from sunlight and while it is less variable in character and much bluer than sunlight it is by no means constant. Overcast skies, bright clouds, and immediate surroundings also alter the resultant light which finds its way into buildings. Ives in collecting the data of Koettgen, Koenig, Vogel and his own showed that sunlight approximates in spectral character the light from a black body at 5,000° absolute C. He has plotted the data obtained by Koettgen, Nichols and Franklin, Crova, Vogel and himself on measurements of the spectral character of blue skylight and draws a mean curve, thus establishing an average blue skylight. Later considerations indicate the apparent black body temperature of the sun to be in the neighborhood of 5,500° to 6,000° absolute C.

Some years ago Ives and Luckiesh produced a colored screen by means of two glasses and an aniline dye which altered the light from a tungsten lamp operating at 1.25 watts-per-candle (7.9 lumens per watt) to clear noon sunlight quality. Of course

this was accomplished at the expense of great absorption. With the aid of chemists a glass was made which took the place of the two glasses. A dyed gelatine film was still required, however. Since that time the original screen has been considerably altered. With the advent of the new gas-filled tungsten lamps operating as high as 22 lumens per watt changes have been made recently under the direction of one of the authors with the result that the screen is now wholly of glass and has been produced in various forms, so that various kinds of daylight are now obtainable. The procedure and results are discussed in subsequent paragraphs.

Before entering upon the theoretical and practical production of artificial daylight it will be of interest to discuss, from the standpoint of color-value, the relative operation of the new and old types of tungsten lamps, namely, the gas-filled and the vacuum lamps. Some idea of the color of the light from a tungsten filament was gained from a knowledge of its luminous efficiency expressed in lumens per watt when all filaments were operated in evacuated bulbs. The vacuum lamp operating at 1.25 watts per mean horizontal candle produced 7.9 lumens per watt. Lamps of larger sizes were operated at a somewhat higher efficiency. The development of the tungsten lamp filled with an inert gas has increased the luminous efficiency to as high as 22 lumens per watt, at the present time, with considerable promise of higher efficiencies to be attained soon. However, luminous efficiencies of the new lamp do not indicate the same relation to color-value as in the case of the vacuum lamp. In other words, a gas-filled lamp operating at a given lumens per watt efficiency will emit a whiter light than a vacuum lamp operating at the same luminous efficiency. This is exemplified in the data given in Fig. 1. Here are shown the relation of the luminous efficiencies of two lamps of different types for a color-match, throughout a wide range of color-matches. The vacuum lamp was a 40-watt. 110-volt tungsten lamp which operated normally at 1.25 watts per mean horizontal candle or at 7.9 lumens per watt. The gas-filled lamp was a 750-watt, 115-volt lamp operating normally at about 14 lumens per watt. The data are accurate to not more than a few per cent., owing to the difficulties encountered in mak-

ing the measurements. It will be noted that the gas filled lamp when operating normally at 14 lumens per watt emitted light of the same spectral character or color-value as that from the older type vacuum lamp operating at 18 lumens per watt. This is readily explained in that there are losses of energy by conduction through the gas in the gas-filled lamp which require that the filament be operated at a higher temperature in order to obtain the same luminous efficiency as is obtained in a vacuum lamp operating at a lower temperature without any appreciable losses by conduction.

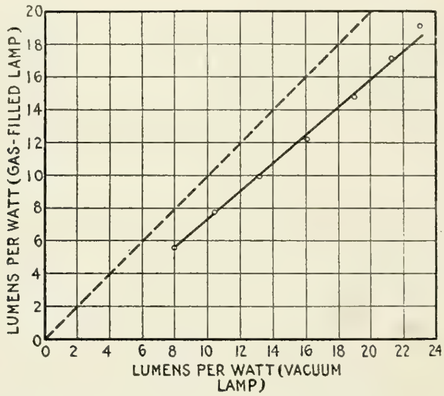

Fig. 1.—Relation between the luminous efficiencies of a vacuum tungsten lamp and a gas-filled tungsten lamp for various color-matches.

It should be mentioned in passing that luminous efficiency is properly expressed in lumens per watt and that it is now more desirable than ever to adopt this means of rating owing to the increased diversity of so-called reduction factors, namely, the ratio of the mean spherical to the mean horizontal candle-power values.

THE SUBTRACTIVE METHOD OF PRODUCING ARTIFICIAL DAYLIGHT.

Ideal Screens.—An illuminant to be used in the development of an artificial daylight unit must have a continuous spectrum, or one practically so; and of course it should be as near to daylight as possible to begin with. By the subtractive method daylight quality is obtained by absorbing those rays present in greater pro-

portion than they are found in daylight. This method is wasteful of light and therefore an illuminant for which this necessary absorption is small is to be desired. The spectral energy distribution is of prime importance and must be accurately determined. In Fig. 2 are shown the various distributions of energy in the visible spectra of three tungsten lamps operating at different efficiencies. These are plotted in the customary manner with the values at 0.59 μ made equal to 100 and are compared directly with the distributions of energy in clear noon sunlight and light

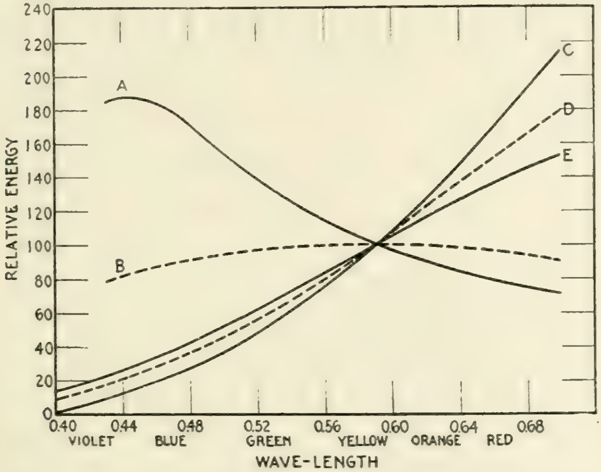

Fig. 2.—Spectral energy distribution of radiation from tungsten lamps compared with blue skylight, A, and sunlight, B; C, tungsten vacuum lamp, 1.25, w. p. m. h. c., 7.9 lumens per watt; D, tungsten gas-filled lamp 0.7 w. p. m. h. c., 15.3 lumens per watt; E, tungsten gas-filled lamp, 0.5 w. p. m. h. c., 22 lumens per watt.

from blue sky. In this portion of the paper these two kinds of daylight will be treated in parallel. By the method under consideration rays present in excessive amounts are absorbed by the colored screen so that the rays transmitted are present in the same proportions as in sunlight or skylight, depending upon which is to be imitated. In all available artificial illuminants the amount of red, yellow and orange rays present exceeds that in sunlight or skylight. It is therefore first necessary to choose a point in the extreme blue beyond which the light will have little practical importance and from this point to alter the light so that it has the required spectral distribution. The choice of this

point is quite arbitrary and is determined largely by experience. The shorter the wave-length of this starting point the greater must be the absorption for the longer wave-lengths. Wave-length 0.42 μ will meet the most exacting requirements and for only rough approximations of daylight, 0.45 μ is a satisfactory starting point. It will be found of interest for several reasons to study the effect of choosing either of these points.

An ideal absorbing screen is one that has a transmission of 100 per cent. at the extreme short wave-length chosen and one that reduces the intensities of the rays of longer wave-length just enough to produce a resultant distribution of energy similar to that in the daylight to be matched. This screen will of course differ with the various illuminants and with the character of the daylight to be imitated.

In Fig. 3 are shown the ideal screens to be used with tungsten

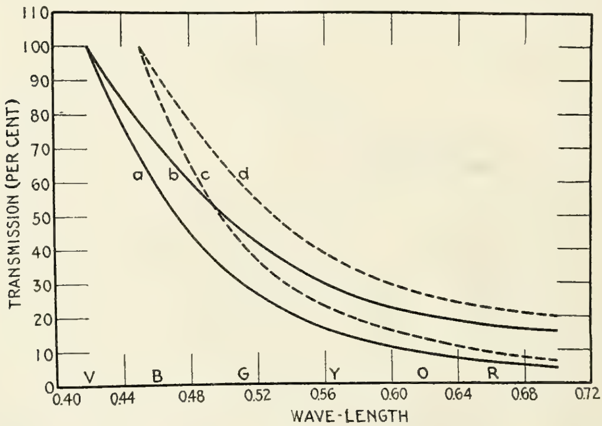

Fig. 3.—Ideal screens for producing "average daylight" (noon sunlight.)
a, screen for 1.25 w. p. m. h. c. tungsten lamp; transmission = 100% at 0.42μ.
b, " " 0.5 " " " " = 100% at 0.42μ.
c, " " 1.25 " " " " = 100% at 0 45μ.
d, " " 0.5 " " " " = 100% at 0.45μ.

lamps operating at 7.9 and 22 lumens per watt respectively for the purpose of producing artificial sunlight and skylight. (The gas-filled lamp operating at 22 lumens per watt has a 1,000-watt concentrated filament which operates in a nitrogen atmosphere.) Four ideal screens are computed for each lamp—two for sunlight and two for skylight. One of each pair of screens is made

totally transparent to energy of wave-length 0.42 μ, the other being totally transparent at 0.45 μ. Energy of wave-lengths shorter than these is neglected in each case. Screens *a* and *b* will of course produce closer approximations to noon sunlight than screens *c* and *d* and should be closely approached by an actual screen where accurate results are desired.

In Fig. 4 corresponding screens for the purpose of producing

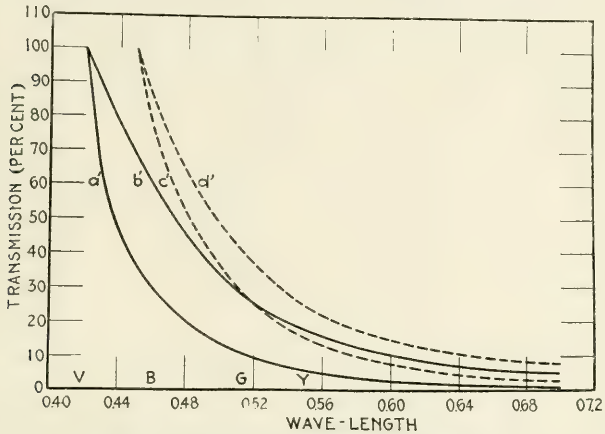

Fig. 4.—Ideal screen for producing "skylight."

a′, screen for 1.25 w. p. m. h. c. tungsten lamp; transmission	= 100% at 0.42μ.
b′, " " 0.5 " " " "	= 100% at 0.42μ.
c′, " " 1.25 " " " "	= 100% at 0.45μ.
d′, " " 0.5 " " " "	= 100% at 0.45μ.

skylight quality are shown. These screens absorb more light than the corresponding ones in Fig. 3, for the reason that relatively more blue and green rays are found in skylight than in sunlight. This necessitates a considerably greater absorption of the long-wave (red, orange, yellow) energy.

DAYLIGHT EFFICIENCY.

All visible rays being present in the radiation from a tungsten lamp it is evident that it has a certain daylight efficiency. That is the radiation can be considered to consist of light of the same quality as sunlight (or skylight) upon which has been superposed a yellow light with the result that the total light is of an unsaturated yellow color. The ratio of the value of the sunlight (or skylight) component to the total light represents the

sunlight (or skylight) efficiency of the illuminant. It is obvious that the daylight efficiency of the incandescent tungsten lamp increases rapidly with the filament temperature.

In Fig. 5, *e* represents the spectral luminosity curve for the tungsten lamp operating at 7.9 lumens per watt. If the ordinates of this curve be multiplied by the transmission values of the ideal screens in Figs. 3 and 4 at corresponding wave-lengths the sunlight and skylight efficiencies are directly obtainable. For instance the area under *e* represents a given amount of light. This

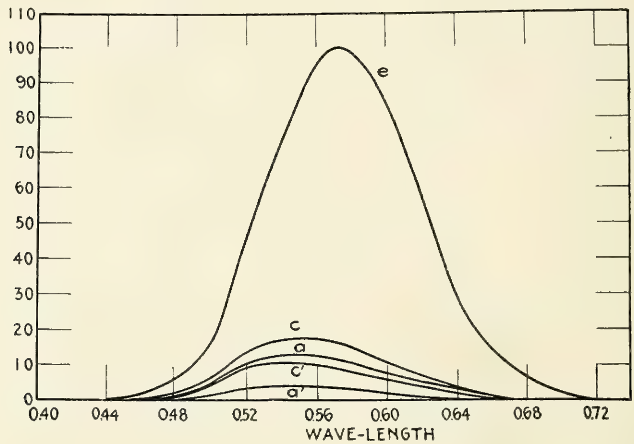

Fig. 5.—Daylight efficiencies of tungsten lamp operating at 7.9 lumens per watt.

e, spectral luminosity curve for this source.

a, reduced luminosity due to screen a which transmits accurate sunlight quality.

c, " " " " c " " approximate sunlight quality.

a′, " " " " a′ " " accurate skylight quality.

c′, " " " " c′ " " approximate skylight quality.

curve is reduced by screen *a* to the value shown. The ratio of the area under curve *a* to the area under curve *e* represents the transmission coefficient of screen *a* for tungsten light produced at 7.9 lumens per watt. This ratio also represents the sunlight efficiency of this tungsten light.

In Fig. 6, *e′* represents the spectral luminosity curve for the high efficiency tungsten lamp operating at 22 lumens per watt. The reductions of the area under curve *e′* produced by the various ideal screens represented in Figs. 3 and 4 are shown and from the areas the sunlight and skylight efficiencies are determined.

In Table I are shown the numerical values of the sunlight and skylight efficiencies of the two tungsten lamps considered. The values in this table can also be considered as representing the transmission coefficients of the ideal screens already described for the particular tungsten lights which are associated with them. The values of the sunlight efficiencies presented in this table are very much lower than those given by Ives several years ago. This difference appears to be accounted for by the fact

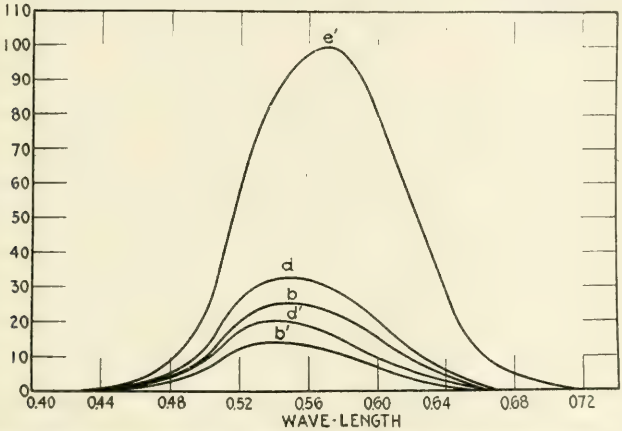

Fig. 6.—Daylight efficiencies of tungsten lamp operating at 22 lumens per watt.
e′, spectral luminosity curve for this source.
b, reduced luminosity due to screen b which transmits accurate sunlight quality.
d, " " " " d " " approximate sunlight quality.
b′, " " " " b′ " " accurate skylight quality.
d′, " " " " d′ " " approximate skylight quality.

that he used a daylight taken from the work of Nichols which has been found to be considerably less blue than the mean value of the results of various observers which have since been collected by Ives.

TABLE. I.—Daylight Efficiencies.
(Transmission coefficients of ideal screens).

Source Tungsten lamp operating at (lumens per watt)	Noon sunlight efficiency		Skylight efficiency	
	equality at 0.42μ	equality at 0.45μ	equality at 0.42μ	equality at 0.45μ
7.9	Screen *a*	Screen *c*	Screen *a′*	Screen *c′*
(vacuum lamp)	14%	18%	4%	9%
22.0	Screen *b*	Screen *d*	Screen *b′*	Screen *d′*
(gas-filled lamp)	25%	33%	13%	19%

TABLE II.—Efficiencies at which Daylight Can be Produced.

Source	Ideal screen	Character of transmitted light	Transmitted lumens per watt
Tungsten lamp (vac)	*a*	accurate sunlight	1.1
operating at	*c*	approximate "	1.4
7.9 lumens per	*a′*	accurate skylight	0.3
watt	*c′*	approximate "	0.7
Tungsten lamp (gas)	*b*	accurate sunlight	5.5
operating at	*d*	approximate "	7.3
22 lumens per watt	*b′*	accurate skylight	2.9
	d′	approximate "	4.2

In Table II the foregoing data have been transformed to another basis of consideration. The luminous efficiencies of the artificial sunlight and skylight have been computed from the luminous efficiencies of the tungsten lamps and the transmission coefficients of the corresponding ideal absorbing screens. It is here seen that artificial noon sunlight, or "average daylight" as it has been called, can be produced by the new high efficiency tungsten lamps at a luminous efficiency of 5 to 7 lumens per watt or in other words at a luminous efficiency not much lower than that at which the older type of tungsten lamps operate. Skylight efficiencies are of course much lower. It is thus seen to be practical to obtain daylight for general lighting by using a proper glass with the new tungsten lamps.

THE ADDITIVE METHOD OF PRODUCING ARTIFICIAL DAYLIGHT.

Another method producing artificial daylight is found in the addition of two or more lights of proper spectral character. If two lights are used they may be said to be complementary to each other. It is found that on adding the light from a mercury-vapor arc to that of the incandescent tungsten lamp in proper proportion a white light is obtained. This resultant light while satisfactory for many purposes is not an accurate reproduction of daylight because of the gaps in the spectrum of the mercury-vapor light. Another example of the additive method is in the use of the fluorescent reflector with the mercury-vapor lamp. This reflector by its property of fluorescence adds red rays thus greatly improving the quality of the light. One of the authors has

developed a scheme of coating the interior of an opaque reflector having a proper surface with a permanent transparent coloring which adds to ordinary tungsten light some blue and blue-green rays, thus improving the light in its approach toward daylight. The same scheme is being applied to the inner surface of a prismatic reflector by means of coatings convertible into glass thus greatly improving the light. The latter scheme has been employed by a foreign manufacturer although apparently only perishable coatings have been used. These are examples of the additive method but, with the exception of the first case, the subtractive method is primarily involved.

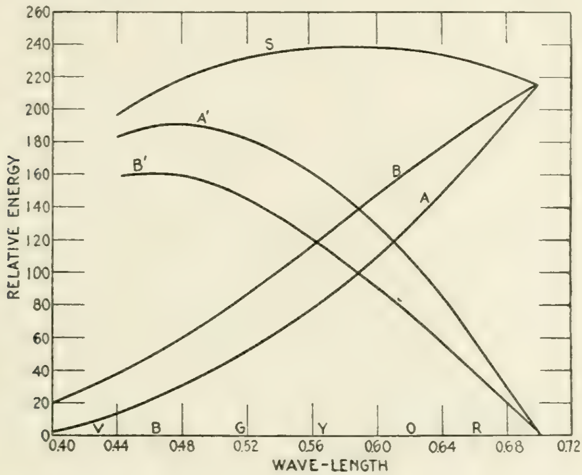

Fig. 7.—The additive method of producing artificial sunlight. S, sunlight; B, tungsten lamp at 22 lumens per watt; A, tungsten lamp at 7.9 lumens per watt; B + B′ = artificial sunlight; A + A′ = artificial sunlight.

The theoretical consideration of the additive method is shown in Fig. 7. The spectral distribution of energy in sunlight and the two tungsten lamps operating at 7.9 and 22 lumens per watt are shown in S, A and B respectively. These are plotted with their energy values at 0.70 μ equal. This point is near the extreme limit of visibility for long-wave energy. By subtracting the ordinates of A and B respectively from the ordinates of S and plotting the remainders the curves A′ and B′ are obtained. These curves are complementary to A and B respectively, that is

the light produced by A when added to the light produced by A′ gives the same amount of light and of exactly the same character as the light produced by S. By multiplying the ordinates of the curves S, A and B by the light-producing values of energy of corresponding wave-lengths the curves in Fig. 8 are obtained. On integrating these curves it is found that the areas under S, B and A are respectively 100, 50 and 33. Thus it is seen that equal amounts of tungsten light (at 22 lumens per watt) and light of such a character as B′, Fig. 7, would produce sunlight quality. However, one part of light from the old tungsten lamp (7.9 lumens per watt) must be added to two parts of light

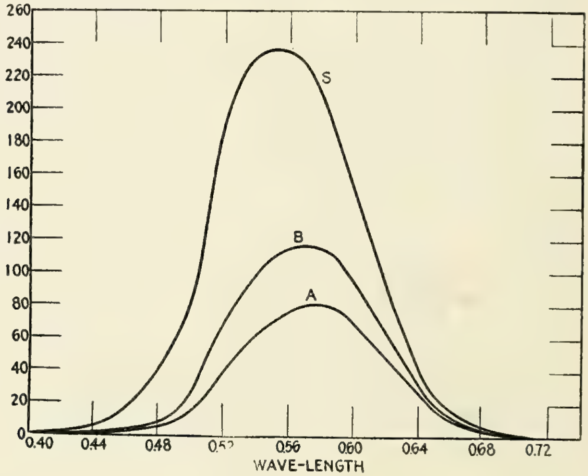

Fig. 8.—Relative spectral luminosity curves for energy distributions shown in Fig. 7.

of the character of A′, Fig. 7 in order to produce artificial sunlight. These data have proven of value in estimating mixtures of colored lamps for producing proper illumination for paintings, etc.

ON THE ACTUAL PRODUCTION OF ARTIFICIAL DAYLIGHT.

After computing the ideal absorbing screen for producing daylight of a certain character the next step is to make this screen a reality. To begin with a general knowledge of the transmission characteristics of various colored glasses is necessary. This knowledge may be extended as necessary.

Let the problem of developing a color screen which will produce artificial blue skylight when used with a new high efficiency tungsten lamp operating at 22 lumens per watt be considered first. A practical solution of the problem will result in a light fulfilling the requirements of an accurate color-matching unit suitable for many purposes for which skylight is used. Modifications of this unit will result in artificial daylight of various qualities. After determining the spectral energy distribution of the incandescent tungsten light as shown in Fig. 2, the ideal absorbing screen which will properly alter this light to skylight quality is computed. The transmission of this screen for energy of various wave-lengths is shown in *b′*, Fig. 4. The practical problem now resolves itself into producing a glass which closely approximates this screen. Obviously it will appear of a blue-green color when viewed by transmitted daylight. Those experienced in practical color science can readily select glasses which show promise. The method from here on is largely "cut and try." A favorite method has been to select or make glass which nearly fulfils the requirements and finally correct this by means of a dye in gelatine. Many dyes have sharp absorption bands and there are so many dyes available that there is no difficulty in finding one that will add the final touches to the screen. However, dyed gelatine is unsatisfactory for commercial purposes, for at best it lacks the durability of glass and most dyes fade rapidly under heat.

After making up an experimental glass it is desirable to have various thicknesses for only a certain density will best answer the purpose. Samples can be ground to various thicknesses and polished or a wedge can be made in one piece. Various thicknesses can thus be obtained for spectrophotometric analysis. A method involving fewer measurements which appears to be sufficiently exact is to determine the transmission for various wave-lengths at one thickness or density. On a numerical abscissae scale plot, thickness and on a logarithmic ordinate scale, plot transmission values. If the spectrophotometric measurements are made in such a manner that the reflection from the glass surfaces is eliminated, this plot will give a series of practically straight lines meeting at the same point represented by 100 per

cent. transmission for zero thickness. The theory is as follows: Let I be the intensity of the light of a certain wave-length after it has passed through a colored glass of thickness, d, and the original intensity be represented by I_0, then

$$I = I_0 e^{-\epsilon d}$$

represents the relation between the intensity of the transmitted light and the thickness of the glass.

Then $$\text{Log} \frac{I}{I_0} = \log T = -\epsilon d \log e,$$

where k is a constant, different for various wave-lengths. In length considered and ϵ is called the extinction coefficient. It is thus seen that

$$\text{Log } T = k\,d,$$

where k is a constant, different for various wave-lengths. In other words, the logarithm of the transmission coefficient for light of a given wave-length is proportional to the thickness of the colored glass. Thus a spectrophotometric analysis need be made for only one thickness, for by drawing straight lines meeting at the proper point the transmission curve for any other thickness can be obtained directly from these lines with sufficient accuracy for the purpose. In determining the transmission coefficients for various wave-lengths for this given thickness of glass care must be taken to eliminate the reflection of the glass surfaces. If this is not done the straight lines must be drawn to a point on the ordinate axis corresponding to a transmission of about 0.92, thus correcting for the reflection of light from two surfaces of the sample of glass. The equations given above must be altered as follows when surface reflection is included in the spectrophotometric data:

$$I = (1-R)^2 I_0 e^{-\epsilon d},$$

where R is the reflection coefficient of a glass surface for normally incident light. This and other factors vary with the wave-length so that a more general condition is represented by

$$\text{Log} \left(\frac{I}{I_0}\right)_\lambda = \log T_\lambda = 2 \log (1-R_\lambda) - \epsilon_\lambda d \log e.$$

$$\text{Log } T_\lambda = 2 \log (1-R_\lambda) + k_\lambda d.$$

The reflection coefficient of a glass surface for light normally incident is expressed in terms of the refractive index n by

$$R_\lambda = \left(\frac{n_\lambda - 1}{n_\lambda + 1}\right)^2.$$

Substituting this value in the preceding equation we have

$$\text{Log } T_\lambda = 2 \log \left[\frac{4n_\lambda}{(n_\lambda + 1)^2}\right] + k_\lambda d,$$

n varies so slightly for different wave-lengths and the same glass and the refractive indices of different glasses examined are so nearly the same that for this practical purpose the relation can be expressed by

$$\text{Log } T = \log 0.92 + kd$$

when $d = 0$, $T = 0.92$.

Proof that this method is sufficiently accurate for the practical study of glasses for the purpose of producing artificial daylight is shown in Fig. 9. Glasses of five different thicknesses were

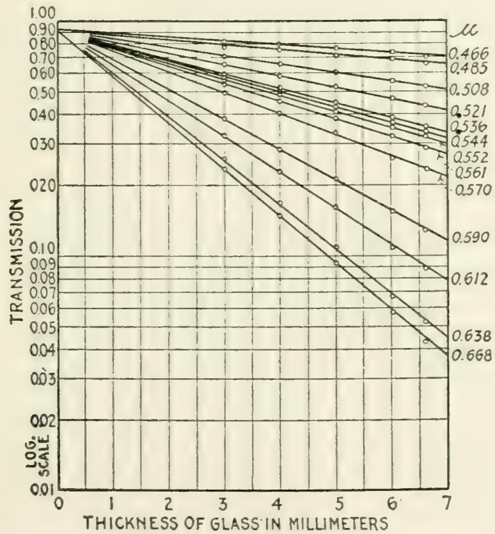

Fig. 9.—Showing relation between transparency and thickness for a specimen of blue-green glass.

accurately studied spectrophotometrically. The straight line relations are shown to hold. Hence instead of making spectropho-

tometric analyses for a number of thicknesses only one thickness need be studied.

The practical solution of the foregoing problem, namely, the production of artificial skylight by means of an absorbing screen used with the tungsten lamp operating at 22 lumens per watt, is shown in Fig. 10. A glass was made which had a transmission curve represented by *x*. The excess of blue-green light was re-

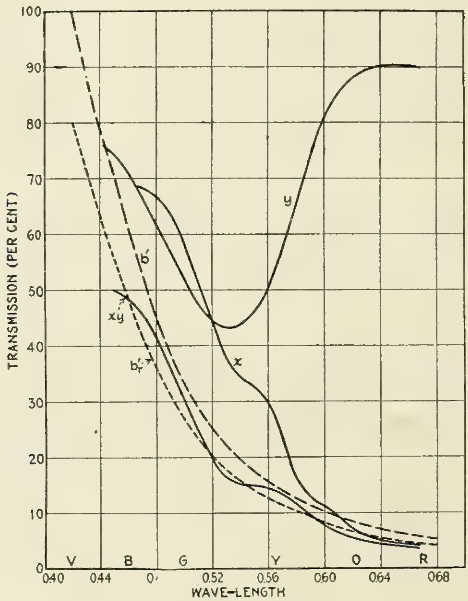

Fig. 10.—Screen for producing artificial skylight.

y,	transmission	of	component A of "skylight" screen.		
x,	"	"	" B "	"	"
xy,	"	"	complete "skylight" screen.		
b′,	"	"	ideal	"	"
br′,	"	"	reduced ideal "		"

duced by means of a component *y* with the resultant transmission of *x* and *y* combined as shown in curve *xy*. This curve is somewhat lower than the ideal curve so that the latter has been multiplied by 0.8, that is, reduced by 20 per cent. This corresponds to placing a smoke glass before the ideal screen. The dotted line represents this reduced ideal curve and it is seen that the actual glass is, for practical purposes, a close approximation to

the ideal screen. In this case accurate artificial skylight is produced at about 2.5 lumens per watt. With this glass and a slight alteration, artificial sunlight is produced at an efficiency of about 6 lumens per watt.

Recent improvements have been made so that the screen is somewhat more efficient and is combined into one piece of glass containing several coloring elements with a result quite like that shown in the *xy* curve just considered. On comparing ideal screens *a* and *b'* shown in Figs. 3 and 4 respectively, it is seen

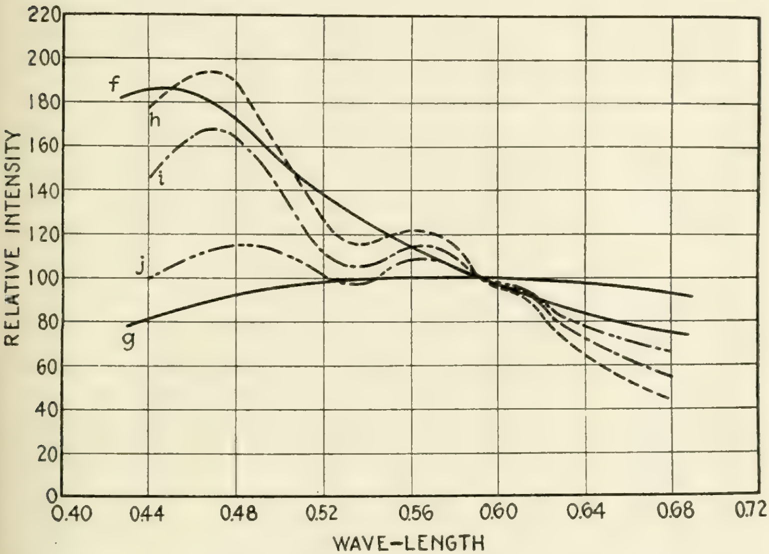

Fig. 11.—The reproduction of various phases of daylight by means of a colored glass and tungsten lamps operating at various efficiencies.

f, energy distribution in blue skylight.
g, energy distribution in noon sunlight.
h, energy distribution in light from tungsten lamp (22 lumens per watt) through colored glass.
i, energy distribution in light from tungsten lamp (15.3 lumens per watt) through colored glass.
j, energy distribution in light from tungsten lamp (7.9 lumens per watt) through colored glass.

that they are practically identical. This means that when the old tungsten lamp is used with the screen *xy*, Fig. 10, artificial sunlight is obtained.

In Fig. 11 are shown the spectral energy distributions of the

light from three tungsten lamps operating at 22, 15.3 and 7.9 lumens per watt as transmitted through screen *xy*. These can be compared directly with skylight and sunlight. The unit has met all practical tests satisfactorily. It has since been still more improved, but a further discussion is unnecessary.

COMMERCIAL UNITS AND THEIR USES.

Luminous efficiency in artificial daylight production is a minor matter in a unit developed for very accurate color-matching. However, there are many cases where light approximating daylight quality is desired for general lighting. Here the wattage is an important consideration, although illuminating engineers and consumers alike must learn that the efficiency of a lighting unit or installation is a measure of how well it fulfils its purpose. This means a broader concept than watts per square foot or effective lumens per watt. If a light source is used for illuminating dress goods and blues cannot be distinguished from blacks, and greens as seen in daylight are confused with yellow and brown fabrics under the artificial light, then the efficiency of the lighting unit or installation falls close to zero in these particular cases. As illuminating procedure becomes more refined and as the efficiency of light production increases more attention is being given to the importance of quality of light. After all quality of light is an important factor in many lighting problems, the remaining details being summed up in distribution. For these reasons glassware for use with tungsten lamps of high efficiency has been developed which will greatly improve the quality of the light, and do so without such an excessive loss of light as would be impractical for purposes of general lighting.

In this development three phases of daylight have been considered with the result that three classes of units have been designed.

The latest color-matching unit accurately imitating a deep blue north skylight when the highest efficiency tungsten lamp (22 lumens per watt) is used produces light of a deep blue skylight quality at about 2.9 lumens per watt. With the multiple lamps of the same type the light corresponds to that of skylight not quite as blue and the luminous efficiency is about 2 lumens per watt. This unit is intended for the purpose of accurate dis-

crimination of color in textile mills, laboratories, color-printing shops, etc. The colored screen is entirely of glass and as there is no excessive temperature rise in a well ventilated unit the glass is permanent and the unit is entirely safe.

The next class of units are intended to imitate clear noon sunlight. This might be considered an average outdoor daylight. There are many cases indoors where the daylight quality is a mixture of sunlight and skylight. This unit produces a satisfactory artificial sunlight for many purposes at an efficiency of about 7 lumens per watt when multiple tungsten lamps are used which operate at an efficiency of about 16.5 lumens per watt. It will be noted that the efficiency at which this artificial sunlight is produced is practically the same as the luminous efficiency of the older type of tungsten lamps. Thus sunlight quality is available for general lighting purposes. The applications for such units are to be found in color factories, lithographing plants, wallpaper and paint stores, paint shops, cigar factories, art galleries, etc.

Other units have been made by combining this colored element with ornamental glassware by casing with light-density opal or by mixing intimately. These units are intended for use in general store lighting where a better quality of light is often desirable than can be obtained from any practical light source available for general store lighting. Any desired step toward sunlight quality can be produced, the magnitude of the step of course depending upon the permissible wattage. By this means a quality of light better than can be obtained from any available light source for general use is produced at a luminous efficiency sufficiently high to meet with favor.

It is futile to attempt to give absorption data on these units because of the variety of densities of the coloring element which can be incorporated in different kinds of white or opal glass. Reference to the sunlight efficiencies given in Tables I and II will give an idea of the absorption; it must be remembered of course that the quality of the light is somewhere between the original tungsten light and sunlight. Obviously a quality of light approximately midway between that from the new high efficiency tungsten lamps and sunlight can be obtained at a higher efficiency than that of the older type of tungsten lamps. It should

be noted that the new lamps not only operate at a much higher efficiency than those of the older type but their light is much nearer to daylight. This means a higher efficiency and a whiter light to begin with thus giving the new tungsten lamps a dual advantage over those of the older type for the purpose of artificial daylight production.

OTHER COMMERCIAL MEANS OF IMITATING DAYLIGHT.

As already stated any light source having a continuous spectrum or one nearly so can be used for the purpose of making artificial daylight. Other desirable characteristics are steadiness of light both as to quality and intensity and high luminous efficiency. The arc lamp early entered the field and has been used considerably although fluctuations in both the color and intensity have been serious drawbacks in some cases. The unit by Dufton and Gardner already noted appears to be the first practical use made of the colored screen for subtractively imitating daylight. Doubtless there have been many more or less approximate reproductions made by others.

Many are familiar with the beautiful white light of the Moore carbon dioxide vacuum tube lamp. No better approximation of average daylight could be desired. The luminous efficiency of the small units for color-matching purposes are quite low, however, and certain difficulties have prevented the general adoption of the longer tube, although wherever this unit has been used the quality of the light appears to be very satisfactory.

In 1909 the mercury-arc lamp was combined with the tungsten lamp in proper proportion with the result that a white light was produced. However, this is only an approximate imitation of daylight, the blue lines of the mercury spectrum supplying the blue rays in which the old tungsten lamp was quite deficient. This combination can not result in a true daylight as considered spectrally because the spectrum of the mercury arc consists of but few lines. The addition of the fluorescent reflector to the mercury-vapor lamp greatly improved this illuminant by adding red rays. This was done largely at the expense of green light.

Early in 1911 Ives and Luckiesh by means of two commercial glasses and an aniline dye produced a screen for use with the

old tungsten lamp operating at 1.25 watts-per-candle for the purpose of producing "average daylight," that is noon day sunlight.

In 1912 R. B. Hussey described a screen for use with an intensified arc which produced sunlight quality. This was done by means of pieces from two colored glasses arranged in a checkerboard fashion with suitable diffusing glasses to mix the light. Owing to the unsteadiness of the arc, spectrophotometric measurements were difficult to make. Therefore a colorimeter developed by F. E. Ives was used. It will be noted that colorimeter measurements are not sufficiently analytical for the purpose of determining the character of the spectrum of a light source. For instance this instrument will indicate that the quartz mercury arc gives approximately white light, yet this light source is worthless where color discrimination is necessary. However, the colorimeter measurements are of interest where the light is known to have an approximately continuous spectrum. This instrument gives readings in terms of red, green and blue components which when mixed produce the same color on a white surface as the illuminant under examination. In Table III are shown the results obtained by this instrument on the Hussey daylight arc unit with other data of interest comparable only in a rough manner.

TABLE III.

Source	Colorimeter reading		
	Red	Green	Blue
Average daylight (noonday sunlight)	100	100	100
Hussey daylight arc lamp	93	111	96
Intensified arc lamp (bare)	147	102	51
Ives and Luckiesh (artificial daylight)	100	93	107
Tungsten 1.25 w. p. m. h. c. (7.9 lumens per watt)	183	96	21
Tungsten 0.65 w. p. m. h. c. (16.4 lumens per watt)	164	102	34
Tungsten 0.50 w. p. m. h. c. (22 lumens per watt)	157	103	40
Tungsten 1.25 w. p. m. h. c. in tinted reflector	145	103	52
Tungsten 0.65 w. p. m. h. c. in tinted reflector	120	102	78
New color matching unit (with 0.65 w. p. m. h. c. tungsten lamp)	80	84	136
Artificial sunlight unit (with 0.7 w. p. m. h. c. tungsten lamp)	110	103	87

The daylight arc examined was a near approach to daylight as far as colorimeter measurements can be trusted, although it

shows an excessive greenish component. This could be easily remedied.

Sharp and Millar by means of colored screens and tungsten lamps also produced a daylight effect. About this time several units, designed to produce artificial daylight, appeared but no examination of these has been made by the authors and no quantitative data are to be found regarding them.

One of the authors has successfully used colored lamps combined with clear tungsten lamps by the additive method as illustrated in Fig. 7. Obviously the color of the light to be added to the clear tungsten lamps is blue-green as shown in Curve A′, Fig. 7. Blue, green, and blue-green lamps were used with success for producing daylight effects in combination with clear tungsten lamps. A notable installation was the lighting of the paintings of the Cleveland Art Loan Exposition where more than 400 colored lamps were used. This is perhaps the first large exhibition of paintings where any attempt has been made to produce a daylight appearance in illuminating the paintings. In order to produce a method for obtaining a light of better color-value for lighting paintings and other colored objects, many experiments have been made with the result that besides the glassware already described metal reflectors have been developed having a tinted surface of such a character as to alter the reflected light to a color complementary to the direct light from the tungsten lamp. Obviously this method results in altering the distribution curve of the reflector producing in general a less concentrated distribution. This indicates that focussing and intensive reflectors of this character should be used instead of those of extensive type. The results obtained with tinted reflectors show that a very good quality of light is obtained at a loss of about 50 per cent. of the original useful light. This represents the extreme case of a reflector with a very deep tint. With coatings of less depth of color the loss of light is less but the improvement in quality of light is likewise less. By changing the shape of the reflector the amount of the altered light can be varied within wide limits. For lighting mural paintings for instance the reflectors have proven very satisfactory. No attempt has been made to reproduce skylight or even sunlight but a very

desirable increase in blue and blue-green rays has been obtained as shown in Table III. The same scheme has been applied to the prismatic reflector, a glass coating being applied in this case. Another instance of the use of colored lamps is found in a large residence in Cleveland where red, green and blue lamps have been combined above diffusing glass in the dining room ceiling to produce various effects, among them being an approximate daylight.

In 1913 Ives adapted a colored screen to the Welsbach gas burner for the purpose of producing artificial daylight.

Pirani has also developed a colored bulb for the tungsten lamp for which it was claimed that daylight quality was produced. Examination of this unit shows that the light is far from average daylight in character. The matter of using the colored glass directly in the bulb might appear to some to be the simplest solution. There are difficulties, however, which have made it appear that the most practicable method is to use the coloring material in the accessory rather than in the lamp bulb. This is especially feasible inasmuch as modern light sources should be equipped with shades or enclosing glassware in order to reduce their excessive brightness.

Interest in the quality or color-value of light is increasing and should continue to grow, for it is of great importance in lighting problems. There is no reason to accept the quality of light from illuminants as they come to us from the manufacturers. There is much to interest the illuminating expert on this side of his problem. It is possible to obtain glassware of a proper tint to suit nearly all requirements on the scientific side from the problem of accurate discrimination of colors to those of a less exacting nature, and on the artistic side toned glassware is obtainable in many tints. These can be supplemented by endless possibilities in silks, or glass shades and reflectors and by controlling the color of surroundings. Little attention has been given to the effect of colored surroundings in altering the color of the useful light. More attention must be paid to this factor for it is wasteful to undergo the expense of producing a satisfactory daylight quality of light and waste it by permitting yellow walls and ceilings to absorb it. It is possible to produce light of daylight

quality by indirectly lighting a room which has wall coverings of a proper color.

This paper is by no means a complete treatise of this subject which is so vital in many lighting problems. An attempt has been made to cover both the theoretical and practical production of artificial daylight and to indicate briefly the development of this phase of lighting procedure. Some proposed units have been examined which have not been included in this paper because they were found to be practically worthless. In the bibliography will be found the most important papers that have a bearing upon the subject.

The authors desire to thank Mr. H. McMullen for assisting in the work and making the drawings which illustrate the paper.

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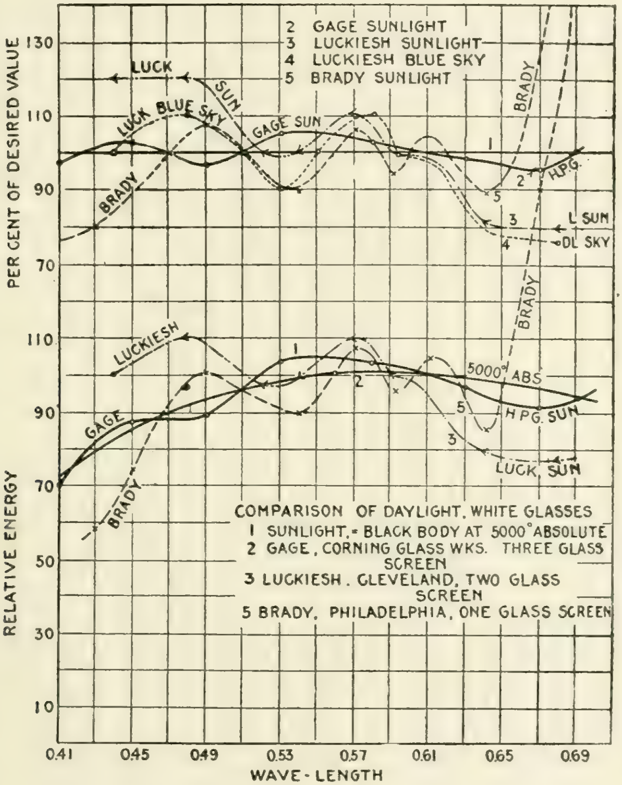
DISCUSSION.

DR. H. P. GAGE: This paper is of very great interest to me because I have been working along similar lines myself for some time, and the theoretical side certainly gives a good idea as to what is necessary to produce daylight screens. The question of getting a glass daylight screen was, I think, first brought up by us about ten years ago when we took a screen to the General Electric Lamp Works at Harrison and suggested that they use it with a carbon lamp to get a sensation white. That same screen, I find, gives a most excellent sensation white when used with the nitrogen filled tungsten lamps, but when it comes to using it with dyed cloths, it does just exactly what we would expect, that is, it is not as good for color matching as the naked source. In getting a screen, the practical question then comes up, how close can one get a daylight screen to approach the theoretical curve, and that is rather a serious problem. The curves given below illustrate the point. One of the curves is the theoretical curve for a black body at 5,000 deg. absolute. I took the data from this paper of Messrs. Luckiesh and Cady and also the paper of Mr. Brady,* and plotted as closely as I could the results which they obtained. In both cases the difference as shown in

* TRANS. I. E. S., vol. IX, No. 8.

the diagrams between the curve desired, blue sky or 5,000 deg. absolute, and the curve given as the final result are plotted. This curve (Curve 3, Fig. A) was obtained by Mr. Luckiesh. The dotted blue curve (Curve 5, Fig. A) was obtained by Mr. Brady—a considerably closer approximation, I believe; but it is to be noted that in Mr. Luckiesh's curve the intensity in the blue is



Figs. A (bottom curves and B (top curves).

very much too high and in the red it falls off a great deal. In Mr. Brady's curve the intensity is low in the region of the extreme blue and high in the red. The importance of the proper intensity in the extreme blue has, I think, been overlooked. We have reason to believe that the intensity in the blue must be at least as high as the curve calls for, in order to get a good color

match with some colors; also there are some dyed fabrics which, if the intensity is too high or too low in the red, cannot be matched. These are particularly colors in which methyl violet is one of the dyeing materials, or any color where there is a band out in the extreme red which ordinarily would not appear.

At the Corning Glass Works we have been able to get a color matching screen, the curve of which approximates the curve from 5,000 deg. absolute in all points within 5 per cent. We found with the glasses which we have tried, that we could get a great deal more accurate result if we used three separate glasses instead of trying to combine all the coloring constituents into one or two glasses. This somewhat reduces the intensity of the light. The final result is, as Mr. Luckiesh has pointed out, an approximation to the correct value, except that the total intensity is reduced just as though a piece of smoked glass were introduced. This curve (Fig. B) shows the percentage differences in each case from what was desired. The differences in the case of skylight that Mr. Luckiesh showed are less than those of his sunlight; in other words he has gotten a better approximation to skylight than to daylight. The results are within about 10 per cent., except in the red where the intensity falls off 20 per cent. (Curves 3 and 4). Now, as a practical matter it is very much simpler to manufacture one piece of glass than it is to manufacture three pieces, and if the closeness of approximation that can be obtained in one piece is sufficient, it is very desirable to do so. There is a serious disadvantage which I wish to point out in having the glass in one piece, and that is, by varying one of the coloring elements in a glass we throw off the approximation to daylight a great deal more than when we vary all of the elements in exactly the same proportion. The difficulties which I have had to overcome I have handled in perhaps a different way than the authors of this paper did, because I was trying to get a very close approximation to daylight without reference to the efficiency or to the number of glasses which it was necessary to use.

Mr. R. F. Pierce: I do not wish to discuss the technical portion of the paper, but inasmuch as particular reference has been made to the commercial application of this device, I think it is necessary to call attention to the fact that some of the terms are

used in a sense in which they cannot be used with any degree of satisfaction in commercial work. For instance, reference is made to skylight and daylight in the sense of standards, which they are not and cannot possibly be.

They vary so widely that any attempt to use them as standards is bound to lead to commercial difficulties. This particularly holds with reference to the device which has been described as available for very accurate color matching in textile mills. If a device of this character were located in a dye works and the representation made to the dyer that it would give an accurate reproduction of north skylight, the first thing he would do would be to compare it with the particular north skylight available and the chances are about 100 to 1 that he would not obtain the same color comparison under the two conditions,—that he would find a discrepancy because the chances of obtaining an average north skylight, an arbitrary average which might be selected for the purpose of comparing an apparatus of this sort, are quite remote on any particular day. As far as the accurate discrimination of color is concerned, one light is as good as another. Any light will enable one to discriminate accurately between colors with reference to their appearance under the same quality of light at any other time, so that all that is gained by an apparatus of this sort is an approximation to what has previously been regarded in that particular trade as a standard, which, in the case of a dye works, is of course north skylight. The dyer himself is very well aware of the fact that north skylight changes considerably in its characteristics and effects from day to day. It is of course perfectly legitimate to emphasize to him the fact that in an apparatus of this sort he obtains a standard which is a true standard, but one should very carefully avoid any presentation of the case which would lead him to believe that he might make a color match under this apparatus and duplicate that match with the particular north skylight available at any moment. I believe that north skylight has been used by dyers more than anything else on account of its being more readily obtainable over a period of time and with a greater degree of uniformity than natural light of any other kind. It is a fact, however, that the light of the tungsten lamp, the gas lamp or direct sunlight is

of quite as much importance in the preparation of textile materials and in the matching of samples of these materials as north skylight. The fact that a piece of goods is matched under north skylight does not necessarily establish the fact that it will always be worn under north skylight, and you may make a perfect match under north skylight and even under artificial light and it be anything but a perfect match and display anything but pleasing color characteristics under direct sunlight.

It might be suggested at this point that in exploiting an apparatus of this character it might be well to call the attention of textile manufacturers to the fact that it would be desirable to have available means of producing a light of approximately sunlight value as well as north skylight value and artificial illuminants as well, and that goods should be compared and inspected under all three with reference to the characteristics they are likely to display when worn. Of course on one side of the street we may obtain approximately north skylight; on the other side of the street, direct sunlight, but it is hardly possible to ask the ladies to change their clothes on passing from one side of the street to the other; they could hardly carry a change of clothes in a vanity bag unless they left their pocket books at home. (Laughter.) So that, in the commercial application of a device of this character, it should always be borne in mind that the term "standard daylight" must be used within the limitation I have stated.

Mr. E. B. Rowe: I think this paper is, in effect a report of progress. We have been able, for some little time, to get desirable illumination *intensities;* in fact, it has been a case simply of determining what the desirable intensity is for the class of service under consideration. We have not, however, up to the present time, been able to get the desired *quality* of light in a great many cases. Now the recent improvement in lamp efficiencies puts us in a position to get quality as well as intensity, and this paper by Mr. Luckiesh and Mr. Cady indicates how it can be done by a perfectly feasible and commercially practicable method.

The real need of units such as are discussed in the paper has been evident for quite a while, and they will have a great variety

of uses. Local conditions will in all cases determine the degree to which the color correction should be carried, and obviously it is necessary to take into consideration any local conditions which will have an effect on the color quality—in the paper the effect of surroundings, both external and internal, is emphasized, I think. Also in the paper, the point is made that it is possible to obtain a so-called white light, of whatever degree we care to consider it, by a combination of colors of certain dominant hues, so as to *seem* white, but a color which would nevertheless fail completely in an attempt to apply it to color matching, with certain colors. It is important therefore, to have the so-called color-correcting unit satisfactory for all ranges of colors, and such units are now commercially available.

Mr. R. F. Pierce: I should like to amplify my remarks and correct the impression which a previous speaker seems to have got from them. I appreciate the fact that the writers of this paper used the terms "standard" and "accurate" in a limited sense, and knew they were doing so. I merely wished to emphasize the fact that the terms must be carefully restricted when applying the results to commercial work and in making representations as to what is to be accomplished by them.

Dr. M. G. Lloyd: I simply want to point out a short-cut method of getting some of these results. As I understand the method of the authors, the areas under the different curves were planimetered, and the ratios taken to get the efficiencies given on the ninth page. The same results can be obtained very simply, if, in place of the curves in Fig. 2, we plot curves which represent equal total illumination for the different illuminants, instead of equal intensity in the yellow. Then to get the maximum possible efficiency for a screen, whose absorption would give an equality at any particular wave-length, it is only necessary to take the ratio of the ordinates of the different curves for that particular wave-length. For example, taking the wave-length 0.45 micron, the efficiency for the gas-filled lamp would be obtained by measuring the ordinates at this wave-length up to the point of intersection of the curves E and B for sunlight efficiency; or E and A for skylight efficiency. It is readily seen that this ratio will be the quantity sought, since an ideal absorbing medium will

let through all the light at the point where the source is weakest, and cut down all the other intensities to the same ratio with the standard as exists for this point.

This method can be used for approximate results with Fig. 2. Since this figure is plotted for equal intensities in the region of maximum sensibility of the eye, and since the curvature of the various curves is not large, the total illumination of the different sources is not greatly different. For instance, if we erect an ordinate at 0.45 micron, and measure off the intercepts on curves C and A, we find these values to be about 16 and 187. Dividing the former by the latter gives 8.5 per cent. as compared with 9 per cent. given by the authors on ninth page of the paper.

Mr. G. H. Stickney: There seems to be considerable demand for a color matching light from tungsten filament lamps. These problems have seemed to classify themselves into the three divisions, which Mr. Luckiesh has mentioned.

It is apparent that store lighting in general does not require as high a degree of accuracy as the textile mill. I have noticed that in a number of cases stores in which the daylight is reflected from a red brick building (which must necessarily distort the color considerably) seem to have little or no difficulty in color matching. Of course, a more accurate color of light is required for the selection of materials which are to be assembled into a garment than is required in the selection of completed clothing.

One of the earliest attempts to standardize color of light was in the manufacture of beer, in order that the product that made from day to day might be the same color. To-day one of the most important industrial applications is in the selection of leather (especially tan) for shoes and novelties; also for the manufacture of oils, inks, paints and many other materials.

It is highly important that all color matching light be reproducible and constant. I believe this is more important than that it should correspond exactly with north skylight, for example, or average daylight. It is well known that the north skylight was selected rather on account of the fact that it is less variable than daylight otherwise obtained, and not because it exactly matches the color of light under which such materials are usually viewed. Everything being equal, any variation from average

daylight might better be slightly toward yellow than toward blue on account of its being more representative. To be sure, dyers who have been trained all their lives to do color matching under north skylight will have a preference for that quality of light. If we have an invariable standard of artificial light which approximates closely to average daylight, I believe that its special advantages would result in training the dyer to work under a standard rather than under north skylight.

MR. M. LUCKIESH (In reply): I wish to state at the outset that the object of our paper has not been to exploit any particular glass but rather it is intended to be a discussion of the matter which could legitimately be covered by the title.

Mr. Gage takes data from our paper, plots it with other data, compares it with the curve for a black body at 5,000° C. absolute and refers to our curves (presumably referring to those in Fig. 11) as skylight and sunlight. In the first place we have not labelled those curves "artificial skylight" or "artificial sunlight" and secondly we state in our paper that these curves do not represent the curves of a final glass. The curves in Fig. 11 were made from a sample which was quite satisfactory and were plotted to show how the quality of light varied with the efficiency of the tungsten lamp used with it. If the object of this paper had been primarily to exploit "daylight" glass, we would have given much more data on the glass itself. I am inclined to favor an average daylight bluer than noon sunlight, that is an average daylight out-of-doors at noon. Sunlight plays a much less important part indoors than out-of-doors. I have also laid especial emphasis upon the necessity of producing a north skylight for color-matching. This has not been advocated very much heretofore. We have found it easy to produce a combination of glasses that would approximate very closely an ideal curve but have not considered it advisable to use more than one glass for practical purposes. After all the degree of accuracy necessary must be determined by practical experience for it is highly improbable that an ideal screen can be accurately produced. Such a screen is certainly necessary. Mr. Gage in giving percentage differences must bear in mind that he is choosing his own standard of sunlight and skylight and comparing our data with his

own. The final glassware that we have advocated has met with practical success, which is assurance that a sufficient accuracy has been obtained. After all, the problem is largely one of approximating average daylight or skylight conditions and as Mr. Stickney says "all color-matching light should be reproducible and constant".

I presented the paper in brief and many of the points brought out in the discussion are considered in the paper itself.

RECENT ADVANCES IN INDOOR GAS LIGHTING.*

BY C. W. JORDAN.

Synopsis: Constant improvements have been made in gas lighting appliances and their accessories within the past few years. These improvements have been spurred on by the necessity of providing for gas lighting higher efficiency, greater convenience and greater reliability in order that it may hold its own in the lighting field. Mantle improvements and the direction of future research work in securing higher visible radiant efficiency are discussed. Gas daylight producers have recently been introduced. A description of various types of automatic and distance igniters for indoor gas lamps is given and attention is called to a new type of magnet valve of ingenious design. Developments in multiple and single burner low-pressure gas lamps are discussed. High pressure lighting is dealt with briefly and the efficiency of several lamps given. Various types of direct, semi-indirect and indirect lighting fixtures are discussed, as well as the practical application in the form of lighting installations.

INTRODUCTION.

Within recent years gas companies and appliance manufacturing companies have energetically attacked the problem of improving the service given by gas lighting appliances. As a result of their united efforts, both from the viewpoint of the appliance itself as well as improving and standardizing the physical and chemical characteristics of the gas consumed, a fresh impetus has been given to gas lighting.

It does not suffice to make improvements if the public is prejudiced from any past experiences; the public must be educated and impressed with the meritorious features of new appliances and inventions as compared with those of the past.

A great deal of unjust criticism of gas as an illuminant is due to the fact that people attempt to utilize it with antiquated burners and accessories, or persist in using cheap inefficient mantles.

With the proper utilization of modern and approved facilities, such as reliable lamps, automatic distance ignition devices, durable mantles, etc., gas is a highly efficient, satisfactory and convenient form of light source.

* A paper read at a meeting of the New England Section of the Illuminating Engineering Society, March 27, 1914.

MANTLE IMPROVEMENT.

Since the inception of the practical incandescent gas mantle there has been no radical improvement over the original chemical substance used — thorium-cerium oxides. The improvements which have been made are those of a physical nature and are very ingenious. Manufacturing facilities have been improved and obstacles which at first seemed insurmountable have been overcome.

Perhaps the greatest recent improvement has been the development of the artificial fiber mantle.[1] This type of mantle is manufactured from an artificial fiber base, the physical structure and chemical composition of which is predetermined and uniform. Impurities often found in cotton fibers and ramie fibers, such as silica, alumina, etc., are entirely absent, which eliminates many manufacturing troubles and insures a more uniform product. The fibers are continuous and solid, a factor of importance in determining the strength of a mantle.

The physical characteristics of a mantle depend largely upon the original fiber base used. Cotton and ramie fibers are comparatively short in length, hollow and often flattened and badly distorted. Upon igniting the saturated fiber the mantle ash obtained is a remarkable reproduction of the original organic fiber. It is obvious, therefore, that a mantle produced from short hollow fibers will have less strength than one produced from continuous solid fibers. Artificial fiber mantles are very flexible (upright mantles) and contact of the fingers with the upper portions will not result in breakage. In matters of life and color changes in the mantle on burning it is superior to either cotton or ramie fiber mantles. Cotton fiber mantles shrink greatly and show an appreciable loss in candle-power after several hundred hours burning; the color of the light becomes whiter and the fragility of the mantle greater.

Ramie fiber mantles maintain their candle-power much better and show but little shrinkage. The mantle, however, becomes hard and brittle on long continued burning, with high mortality.

Artificial fiber mantles, upright or inverted, show no noticeable shrinkage after 1,000 hours burning, and the candle-power

[1] Gubraudsen, S., Artificial Fiber Mantles; *Proceedings* N. C. G. A., 1912.

remains near the initial. The deterioration in strength and flexibility is not nearly so rapid, nor as great, as with cotton or ramie fiber mantles.

ADVANCES IN THE KNOWLEDGE OF THE PHYSICAL CHARACTERISTICS OF MANTLES.

A complete knowledge from scientific study of the physical characteristics of a light source is a great asset, if not an essential, in the development of improvements in the efficiency and physical strength of the illuminant. Recent study has resulted in some very interesting facts regarding the physical properties of mantles.

Regular tests show in general that a deterioration in candle-power and strength occurs when the mantles have burned for definite periods. There has been a great deal of speculation, but little or no experimental work, to determine the exact cause or causes for these deteriorations.

The first investigations made[2] consisted in magnifying several meshes of a new mantle and making observations after definite burning periods. It is known that candle-power deteriorations and changes in the physical strength of mantles of different types on continuous burning are variable. Consequently a mantle of each type—cotton fiber, ramie fiber and artificial fiber—was selected and microphotographs made initially, after burning 500, 1,000, 1,500, 2,000, 6,000 and 6,680 hours respectively.

Fig. 1 (*a*) shows the meshes of a cotton fiber mantle initially (mantle hardened) and (*b*) after burning continuously for 3,700 hours.

The effect of continuous burning on the fibers can be readily observed. Loose fibers are broken and many changes in the twisted strands are apparent. From this it would be expected that candle-power deterioration and other changes would be very marked and the results of numerous tests have confirmed this supposition.

Fig. 2 (*a*) shows the meshes of a ramie fiber mantle initially and (*b*) after burning continuously for 6,680 hours.

The individual fiber components of this type of mantle are very numerous and are held together rather loosely. After

[2] Bond, Chas. O., Photometry of Incandescent Gas Lamps; *Proceedings* A. G. I., 1912.

burning 6,680 hours continuously only several of the small fibers were found to be broken. There were no other apparent changes.

Fig. 3 (*a*) shows the meshes of an artificial fiber mantle initially and (*b*) after burning 6,680 hours.

A close examination of the individual fibers of the various meshes fails to reveal one instance of breakage, distortion or volatilization of the oxides after this long burning period. This is a remarkable performance.

It would seem then that the thorium-cerium oxide at ordinary flame temperatures is a stable compound and that it would only be necessary to incorporate these oxides into mantle form and protect them from unnecessary shocks, such as often occur when an improper mixture of gas and air is obtained on first lighting, to secure an indestructible mantle.

However, records show that certain physical changes occur in incandescent mantles, the most prominent of which are increasing fragility and progressive losses in candle-power.

The strength of a mantle before and after burning as indicated by the regular bumping machine test sometimes shows confusing results; but it is fairly well established that a mantle which has burned continuously for a long period is very much more fragile than immediately after being burned off. It has been shown that this is not due to breakage of the minute filaments in the mantle and consequently it must be due to some internal change in the component parts.[3] The observation of such physical changes necessarily involves the use of a high magnification lens. The lens used had a focal length of 1.90 mm., N. A. 1.30, and gave a rated magnification of 1,530 diameters. The individual mantle fibers were embedded in heated Canada balsam, which at ordinary room temperatures becomes solid. In order to secure clear definition, transmitted monochromatic green light was used for illumination purposes.

Three conditions of the fibers of each type were examined: first, when ignited from the nitrate form (in the case of artificial fiber from the hydrate form); second, after hardening; and, third, after 2,000 hours continuous burning.

[3] Jordan, C. W., The Physical Structure of Incandescent Gas Mantles; *Lighting Journal*, April, 1913.

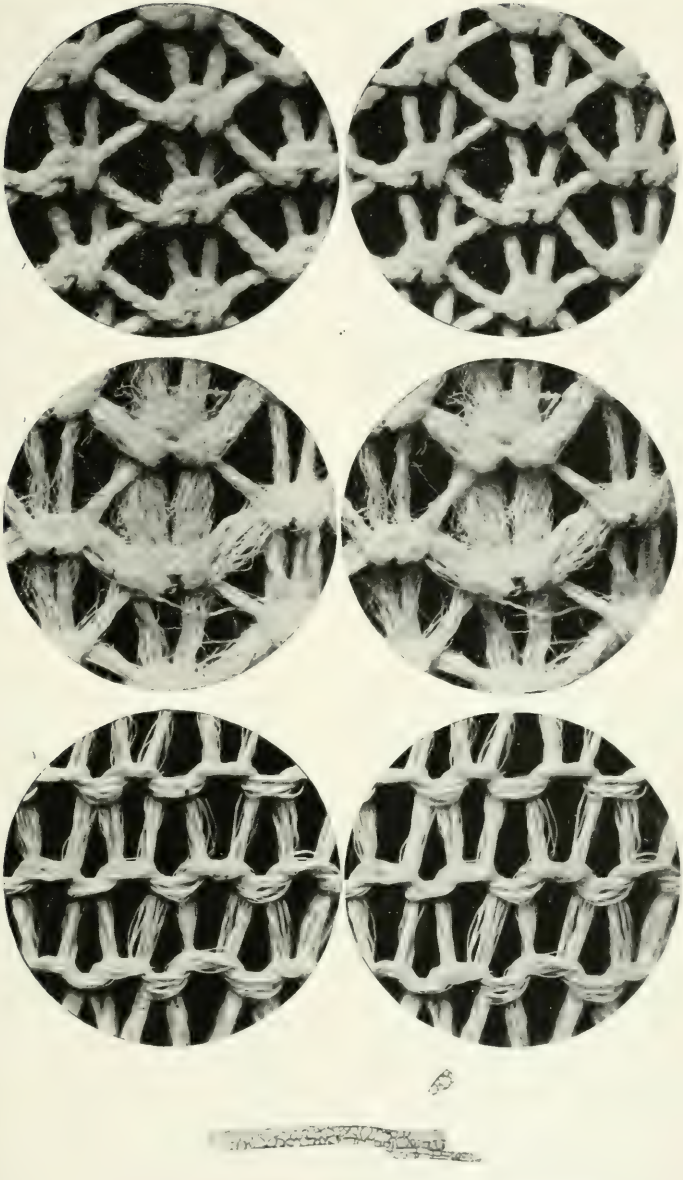
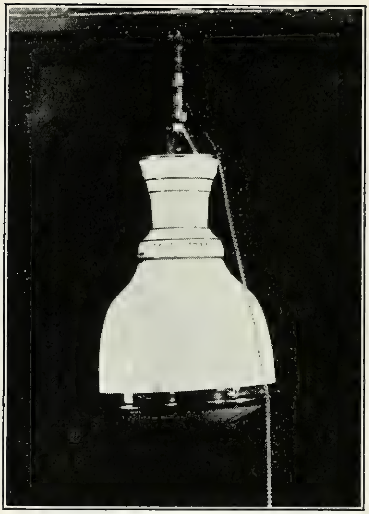


Fig. 1 (top)—Meshes of cotton fiber mantle; Fig. 2 (second row from top)—Meshes of Ramie fiber mantle; Fig. 3—Meshes of artificial fiber mantle; Fig. 3a (bottom)—Crystallization of Rami fiber base mantle ash.



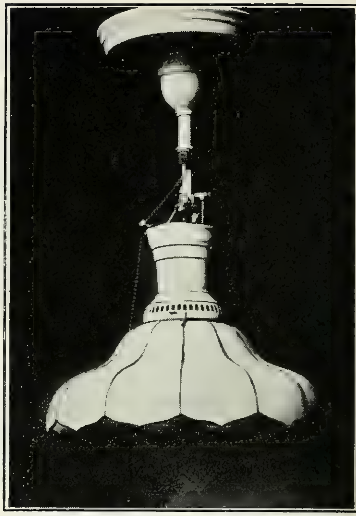
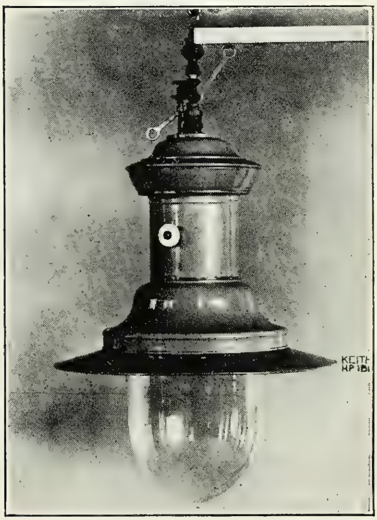


Fig. 4 (left)—Lamp and accessories for producing artificial daylight; Fig. 8 (right)—Large unit single burner lamp with ornamental shade.



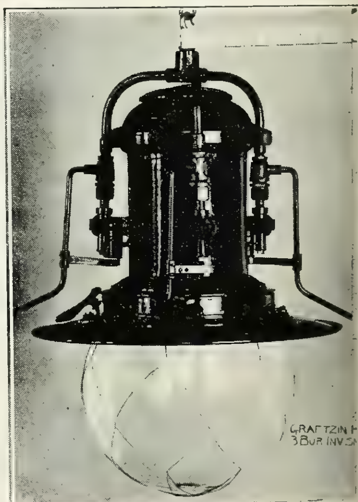


Fig. 9 (left)—Keith high pressure lamp; Fig. 10 (right)—Three-burner high pressure lamp.

Each type of fiber upon ignition presented an appearance almost identical with the striated nature of the original fiber. Observed under transmitted light the oxides were arranged in strata which run parallel and in the same direction as the ordinary fibers and in certain planes allowed the light to pass through more freely than in others.

Filaments of a ramie fiber mantle when hardened showed a change in structure. The fibrous nature was not nearly so prominent and the oxides in many places showed a greater density. Filaments of a hardened artificial fiber mantle appeared dense, transmitted but little light, and showed clearly the definite change in structure.

In the case of the hardened cotton fibers, the changes noted in the other two types were not nearly so prominent, the filaments retaining more or less of their original striated nature. The subsequent shrinkage of this type of mantle may be dependent upon this fact.

The most interesting observations were upon filaments which had burned for 2,000 hours. The filaments of ramie fibers were composed of minute transparent particles closely interlocked and probably crystalline in nature.

The transparent crystalline structure was not so prominent in the artificial fibers, owing probably to their greater thickness, but the outer surface showed unmistakably the same change.

Cotton fibers, separated by agitation in water, were found to be composed of transparent particles slightly smaller in size than those of the former two.

DISCUSSION.

It is known that ordinary white bodies are in reality composed of transparent particles which are nearly always capable of being fused, or in some manner amalgamated to form a transparent mass the color of which may differ greatly from the diffused light of the fine aggregates. An illustration is the salt, copper sulphate, which in masses is a rich blue color. When the crystals are crushed, the more finely divided the particles the whiter does the reflected light become until the point is reached when the powder appears as an ordinary white substance.

Thorium-cerium oxides in combination are examples of white

bodies ultimately composed of transparent particles. When fabrics which have been saturated with the nitrates of these elements are ignited, the resultant oxide appears white to the eye, due to the diffused reflection from the extremely fine aggregates which are loosely combined. The fineness of these particles is probably due to the evolution of gases on ignition and the necessity of all particles combining with oxygen. Under the influence of the high temperature hardening flame these particles tend to fuse together, forming a more compact mass.

After burning the fusion becomes more complete and the transparency greater. In the case of mantles burning for long periods the oxides actually form comparatively large transparent aggregates closely interlocked and which may be crystalline in nature.

The interpretation of these physical properties in terms of loss in strength of mantles is obvious. The difference in the performance of the three types of mantles is due, first, to the physical and chemical properties of the original fibers, and, second, to the difference in the action of the hardening flame on the oxide.

The transparency effect of oxides involves other interesting considerations. If a perfectly transparent disk,[4] say of quartz or glass, be heated to a high temperature it emits but little light in the visible spectrum, because of its absorption, following the radiation laws. If, however, the substance is suddenly cooled so as to become traversed with a great number of fracture planes, upon reheating it emits a fairly intense light until the point of fusion is reached, when it again becomes transparent and the emission of light suddenly ceases.

When a mantle becomes more transparent upon burning, the candle-power losses may be attributed to this factor.

PHYSICAL EXPLANATION OF THE LIGHT PRODUCTION AND POSSIBILITIES FOR FUTURE IMPROVEMENT.

The Welsbach mantle is composed of 99 per cent. thorium oxide and 1 per cent. cerium oxide. Thorium oxide being white in color and the individual particles therefore being transparent, can emit but little light in the visible spectrum when heated, fol-

[4] Wood, R. W., Physical Optics.

lowing Kirchoff's law (a substance emits when heated those wave-lengths it absorbs when cold).

Cerium oxide being a rich yellow color, the absorption band broadening on heating and therefore absorbing the violet, blue and into the green, must emit most of the energy in this region of the visible spectrum.

The addition of small percentages (up to about 1 per cent.) of ceria to a thoria mantle is followed by an increase in intensity of the visible radiations. Further additions of ceria produce proportional decreases in the luminosity because, owing to the high emissivity of ceria, the temperature of the mantle drops so low that the selective emission no longer compensates for the decrease in temperature.[5] This physical explanation of the efficiency of the Welsbach mantle is the theory accepted generally by physicists.

The present methods of producing artificial light are extremely inefficient and the possibilities of improvement are great.

In a normal incandescent gas lamp the proportion of the total gaseous energy which goes to the production of radiation within the visible spectrum is but 0.34 per cent. and with an open flame of 0.082 per cent.[6] By securing an ideal coloring substance for a transparent oxide, so as to reduce to a minimum the radiation in the infra red and ultra violet, the efficiency of a gas mantle could be increased many fold. A small transparent oxide disk, properly colored, should be an ideal radiator in the visible spectrum.

A realization of these possibilities of improvement is giving fresh impetus to research work.

COLOR MATCHING APPARATUS.

In the various textile industries, etc., there has long been felt the need of an apparatus for the production of artificial daylight for matching fabrics and dyes. Ordinary artificial light sources show a deficiency in the blue and an excess in the orange and red of the spectrum.

Recently a method of production of artificial daylight with the use of gas lamps has been worked out by Dr. H. E. Ives and Mr.

[5] Coblentz, W. W., Selective Radiation from Solids; Bureau of Standards Bulletin No. 2, vol. VII. Rubens, *Ann. der Phys.*, 18, p. 725, 1905; 20, p. 593, 1906.

[6] Bond, C. O., A Survey of American Gas Photometry; *Proceedings* A. G. I., 1911.

E. J. Brady.[7] This is an example of the subtractive method of production, consisting in filtering out the excess orange rays by means of blue filter. The apparatus was first worked out in the form of a booth, using a dyed gelatine screen in connection with a blue-green glass. More recently a single blue glass filter has been developed which has many advantages over the booth. A lamp designed to produce artificial daylight is shown in Fig 4.

This approximation of daylight is found to be sufficiently close for all practical purposes. Under it lavenders and purples may be matched perfectly; blues appearing blue instead of black and greens preserve their daylight color.

COLOR EFFECTS.

The color of light from an incandescent gas lamp can be made quite variable without the use of absorption screens by changing the composition of the mantle. While it is true that the efficiency of a gas mantle depends upon its cerium oxide content, this can be varied so as to produce light of different color and still be of a sufficient intensity to be a practical and economical source.

The color change in the light of mantles has found practical application for use in photographic studios, the mantles containing 0.25 per cent. cerium oxide being rich in actinic rays. In home lighting, where a soft golden glow is desired, mantles containing 2 per cent. cerium oxide are used.

AUTOMATIC AND DISTANCE LIGHTERS FOR INDOOR LAMPS.[8]

One of the chief advantages of electric lighting is the convenience and simplicity of control of the lamps. In order to meet the demand for convenience in the lighting of gas lamps and to entirely eliminate the inconvenience attached to the use of matches, distance ignition has become almost a necessity. In spite of the fact that great numbers of mechanisms for this purpose have been patented, there are but few which have proven practical in continued service. The causes of failure are numerous—cock plugs wearing down, lubricant hardening, valves corroding, short life of electric batteries, etc., and methods of overcoming these troubles must necessarily be ingenious.

[7] Ives, H. E., and Brady, E. J., A Gas Artificial Daylight; *Lighting Journal*, 1913.
[8] Gilpin, F. H., Automatic and Distance Lighters; *Proceedings* A. G. I., 1913.

To be practical the lighter must be simple in construction, positive in action and not prohibitive in cost. Some of the types giving satisfactory service are discussed in the following paragraphs:

Pilot Ignition.—The most common method of automatic ignition is the pilot light, consisting of a by-pass which allows a small quantity of gas (about 1/10 of a cubic foot per hour) to pass around the burner. A novel method of pilot ignition consists in running two separate lines to each lamp, one for the main gas supply and the other, a very small pipe, for the pilot. By this method a large number of burners can be controlled from any desired point. However, if the distance of the furthest from the main gas cock is too great their is danger of flash back.

Among the recent improvements in pilot tips has been the development of a tip giving a non-luminous flame, which impinges on the mantle. This eliminates the formation of carbon particles above the tips and in addition these flames are less susceptible to draft than the old type luminous flame.

Catalytic Igniters.—This method of ignition depends upon the properties of platinum-black and similar compounds to cause the combination of hydrogen, carbon monoxide, etc., with oxygen Certain difficulties have been found in practise: in cold rooms the ignition is slow or not occurring at all; exposure to high temperatures resulting in short life of the active material; so that this method of ignition is far from ideal. However, in its recent application to upright mantles the performance of certain mantles has been very promising. A small quantity of platinum black impregnated in a porous non-fusible material is attached to the mantle and thin strips of rhodium black pass diagonally through the center.

By properly placing the active material several mantle igniters had a life of two hundred hours and during that time never failed once to ignite.

Some self-lighting mantles are on the market and are meeting with variable success, depending upon atmospheric conditions and especially upon the kind of gas in use.

While this form of ignition cannot be classified as being entirely successful, there is reason to believe that for certain local-

ities these mantles may be perfected to give efficient satisfactory service. This method of ignition is the simplest and most desirable.

Pyrophoric Igniters.—Pyrophoric igniters depend for their action on the ignition of gas by sparks obtained from the friction of a cerium-iron alloy with a steel abrading surface, such as a small file. When the device is properly designed and constructed, this method of ignition is positive in its action, requiring of course a renewal of the active material after one thousand to fifteen hundred ignitions.

An ingenious application of this principle has resulted in a successful igniter.[a] This device is applicable to inverted lamps using a gooseneck extension piece. The vents of the lamp are turned towards the gas cock. Turning a key on full causes a shower of sparks to ignite a long pilot flame which momentarily shoots across the intervening space into the crown vent, causing ignition. Upon releasing the key a spring turns off the pilot supply, but leaves the main burner supply on.

Another form of igniter consists essentially of a cylindrical steel scraper, or file, against which is held a pellet of cerite by means of a strong spring. The whole is attached to a central shaft or rod and can be moved upward opposite the top of the vents of inverted lamps. In order to light the lamp the shaft is pushed upward and then turned rather quickly to the right. The abrader disengages small particles of the active material, which glow with bright incandescence and ignite the gas. The rod falls back in its lower position and is effectively removed from the hot products of combustion.

Filament Ignition of Gas.—The principle of this method of ignition depends upon the fact that if a very thin platinum wire is heated in a bunsen flame and the gas turned off, upon again turning it on after a few seconds the wire will glow brightly and cause the gas to ignite. The initial heating of the filament is accomplished by the current from dry cells. A positive and successful filament igniter of this type[b] is now on the market.

Upon pressing a button the electric circuit is completed and the initial heating of the spiral platinum-iridium filament starts catalytic action. In series with the igniter the current actuates

an electro-magnet and turns on a flat ratchet disk valve, alternately opening and closing the gas passages. This type of igniter is applicable to both inverted and upright lamps and is fairly simple in construction. The batteries used consist of four dry cells in a single container. A single push button is used for igniting and extinguishing. This igniter has met with success abroad and at a nominal expense gives great convenience in lighting.

Jump Spark Ignition.—This method of ignition depends for its operation upon the principle used in sparking the gas mixture

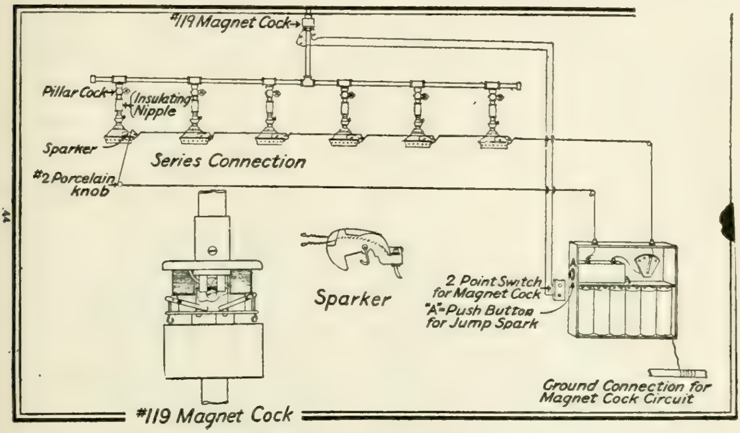


Fig. 5.—Diagram of jump spark ignition of inverted lamps used with magnet valve.

in automobiles. In a modern application to incandescent gas lighting this igniter is used in conjunction with a magnet valve, the same set of dry cells serving to operate both the valve and the igniter. A diagram of the essential connections is shown in Fig. 5. The spark comes from the secondary terminals of a small induction coil. The primary current is supplied by a set of six standard dry cells. The gas is first turned on by pressing the magnet valve push button and the lamp ignited by pressing the jump spark push button. This igniter is positive in its action.

Magnet Valves.—The magnet valve is usually operated with a by-pass integral with it, although the jump spark ignition is sometimes used. Two electro-magnets are connected in parallel,

using the gas piping for a return and are operated by separate push buttons. The cock plug moves back and forth through 60 degrees by the alternate strokes of the armatures of the two electro-magnets on a cam attached to the barrel. The current is

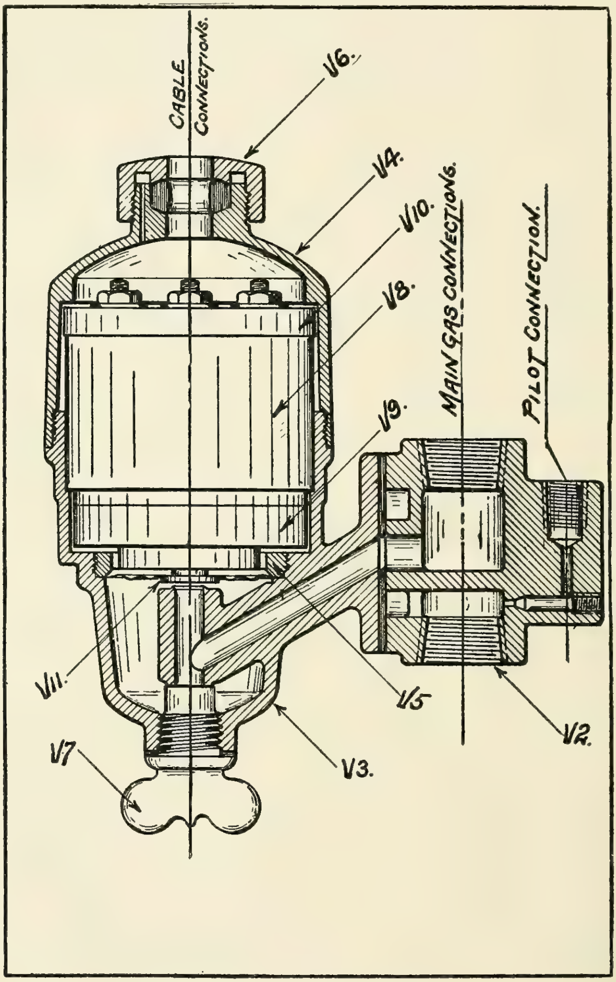


Fig. 6.—Sectional view of magnet valve.

supplied by three or four dry cells, five to six volts potential being required.

Magnet valves are successfully used on indoor arc lamps

requiring little maintenance, one set of batteries under ordinary conditions giving proper service for about a year.

A successful form of magnet valve, applicable to both indoor and outdoor lamps, has recently been developed[c], a sectional view of which is shown in Fig. 6. This valve will work on a single two-volt dry cell. Upon pushing a button the circuit is completed and the current passes through the magnet V-8, attracting and lifting the armature V-9. The magnet is designed so as to retain its magnetism indefinitely, or until a current is sent through in a reverse direction by means of a reverse coil. The raising and falling of the armature operates a gas valve through a diaphragm partition V-11. The gas enters V-2 of the reversible main gas supply connection and passes through the valve and passageways to the gas outlet. A continuous burning pilot is used and is adjustable by means of a screw. The magnet consists of two magnet coils wound upon the same core, one wire from each being connected together and the other two leading to individual push buttons. The current used to build up the magnetic flux is insignificant and only used for a fraction of a second. Therefore, the dry cell used should have practically its shelf life. The commendable features of this valve are that there are no pivot pins or journals to wear, gas is separated from contact with actuating mechanism, and if the valve face wears it can be easily replaced. This design of valve is extremely ingenious and unique and is positive and reliable in action.

Pneumatic Valves.—The operation of this type of igniter depends upon the movement of a cock by vacuum or pressure developed in a small plunger pump and transmitted to the cock by a small flexible hollow tube. Pilot ignition is generally used.

One valve[d] of this type is giving creditable service. The device consists essentially of a hollow brass cylinder in which two pistons connected to each other by means of a rod move to and fro. A brass pin moving in a slot in the cylinder is attached to a connecting rod and rack on the outside. The rack is loosely supported in slots of the two projecting arms and is grooved to move a cylindrical cog which is above it. The shaft of the cam moves in or out according to the direction of the piston through a movement of ¼ inch, shutting off or turning on the gas. With

a properly designed pump and air-tight connections on the transmitting tubes this type of valve is satisfactory and dependable.

Pressure Lighter.—A form of igniter utilizing the energy derived from the pressure of the gas for opening the valve is

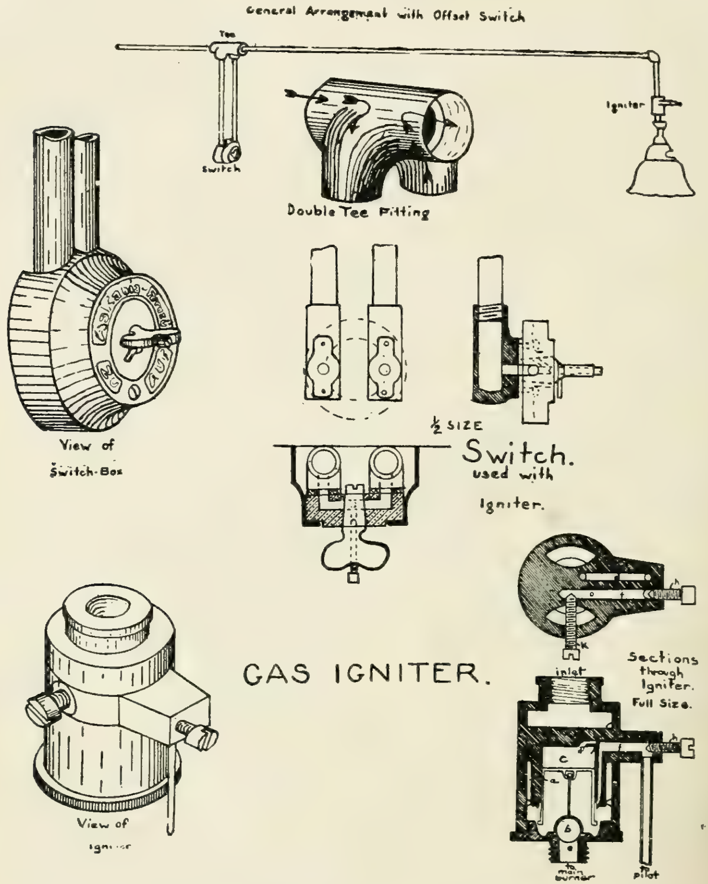


Fig. 7.—Diagram of pressure lighter.

shown in Fig. 7. This device consists of an arrangement by which a light may be turned on or off by a special form of gas cock located at any distance. The gas cock is in the form of a switch which allows a small quantity of gas to pass when turned

to the "off" position. When the switch is turned on the full pressure of the gas lifts a float (*a*) in a small governor-like contrivance above the burner and permits the gas to flow. When only a small quantity of gas leaks past the closed switch the float drops back and extinguishes the lamp, but permits a small quantity of gas to by-pass to the pilot flame. A steel ball suspended from the float seats in the opening (*e*) and forms the valve. The float has a lip on the lower edge which when raised shuts off the gas supply to the pilot. By opening the screw (*k*) the float can be by-passed and the pilot made to burn continuously.

DEVELOPMENTS IN LAMP CONSTRUCTION.

Important improvements in the inverted multiple burner gas "arc" lamps have been made in the past few years. The problem of eliminating certain defects which occur to mantle burners, such as carbonization of mantles, flashbacks, disintegration of metal parts, etc., has received much attention and is rapidly being solved by the gas companies and progressive lamp manufacturers.

Mechanical improvements have and are being evolved for convenient methods of removing and cleaning glassware, replacing mantles, increasing the efficiency, etc., all of which simplify and economize maintenance and upkeep. In construction the general tendency has been to change from the individual gas adjustment for each burner to that of a single gas adjustment for a multiple burner. This type of arc lamp is meeting with great success in that the construction is simple, less expensive and maintenance easier.

There are many gas arcs on the market, a number of which possess commendable features, giving high efficiency and being sufficiently flexible to operate successfully under variable gas conditions.

Low pressure indoor arc lamps can be obtained in unit sizes from 150 mean spherical candle-power to 350 mean spherical candle-power and with the use of reflectors the mean lower hemispherical candle-power is as great as 500.

Typical photometric performances of arc lamps are shown in the following table:

PHOTOMETRIC PERFORMANCES OF GAS "ARC" LAMPS.

Lamp	No. Burners	Globe	M. U. H. C. P.	M. L. H. C. P.	M. S. C. P.	Cons. mixed gas 2.5" press	Lumens per B. t. u. hour
A	3	¼ Frosted	94.0	267.8	180.9	9.65	0.348
A	3	Opal	112.8	186.8	149.8	9.77	0.314
B	5	Clear	138.6	397.0	267.8	17.01	0.306
B	5	Opal	182.4	317.9	250.1	16.98	0.278
C	5	Clear	4.3	479.1	241.7	15.79	0.310

One mean spherical candle-power hour can be obtained on a consumption of 0.05 to 0.06 cu. ft. when using clear globe and 0.065 to 0.075 cu. ft. when using opal globe.

It will be of interest to make comments on the effect of variable gas conditions throughout the country upon the efficiency of various types of lamps.

In order to meet variations such as pressure changes, changes in gas composition, etc., it is necessary for the lamp manufacturer to determine the proper size gas orifice, shape and size of primary air inlets, proper mixing tube, etc., so that a lamp will give maximum candle-power for a standard consumption. These factors being determined it has been shown by a series of careful investigations that the illumination duty per volume of gas varies closely in proportion to the calorific value of the gas, except for a slight elevation or depression, depending upon the theoretical flame temperature.[9] Therefore, on a given consumption the total light output is a function of the calorific value of the gas.

SINGLE BURNER LAMPS.

Probably the most important development in gas lamp manufacture in the past year has been the introduction of a large unit single mantle inverted lamp, filling the gap between the small inverted 60 mean spherical candle-power unit and the three-burner inverted arc lamp. In general the essential dimensions of the lamp are double those of the small inverted burner, the consumption more than twice as great and the efficiency higher.

The mean spherical candle-power varies from 140 to 180, depending upon gas pressure and gas characteristics.

This type of lamp using ornamental reflecting shade is shown in Fig. 8.

[9] Deville, M. Emile Sainte-Claire, The Illuminating Power in Ordinary Incandescent Burners, Etc.; *Proceedings* A. G. I., 1911.

HIGH PRESSURE LIGHTING.[10]

The possibilities of developing high pressure gas lighting has been called to the attention of the gas industry in this country for a number of years. Developments in this form of lighting have been rapid and while installations are far more numerous in Europe than in this country there is reason to believe that it will here become as prominent as low pressure lighting.

Perhaps it might be well to review briefly the fundamental principles of high pressure lighting before dwelling on the recent progress made. An increase in the efficiency of gas lamps of from 40 to 50 per cent. can be obtained by means of using gas under high pressure, usually 2 lbs. to 3 lbs., or by using low pressure gas, and air under high pressure, usually ½ lb. The increase in efficiency is due to the fact that the mixture of gas and air is more intimate and nearly correct and, therefore, the temperature of the flame is increased and also there is a better relation of the mantle to the flame.

When the gas is delivered in the mains under low pressure it is necessary to use a small gas compressor for the first type of high pressure lamps. A common method of ignition is to run a separate pilot line under low pressure and to control the main high pressure gas supply from any desired point by means of a lever cock. This method is not entirely satisfactory if a large number of lamps are used, as the main gas supply line soon fills with air after the gas has been turned off and the development of a pressure lighter became almost a necessity.

An apparatus has been devised which is similar in principle to another lighter[e] now on the market. When the gas is at low pressure the pilot is burning normally, then on increasing the pressure the pilot flashes momentarily and the mantle is ignited. The pilot remains extinguished during the burning of the lamp. On decreasing the pressure the pilot again flashes momentarily and is ignited from the mantle, the main gas supply being extinguished. The pilot subsequently burns at its normal consumption on low pressure.

The mantles used on high pressure lamps must necessarily be of stronger texture than those used on lamps operating at ordi-

[10] Symposium on High Pressure Gas Lighting; TRANS. I. E. S., 1912. Westermaier, F. V., High Pressure Gas Lighting; *Lighting Journal*, 1913, p. 9.

nary gas pressure. A recent improvement has been the use of rag type artificial fiber mantles, giving a life of over 400 hours with practically the same candle-power as initially.

The lamps range in mean spherical candle-power from 300 to 2,000, with the maximum candle-power as high as 4,000. The inverted lamp is the most common type. Enameled reflectors which concentrate a large light flux in the lower hemisphere are generally used.

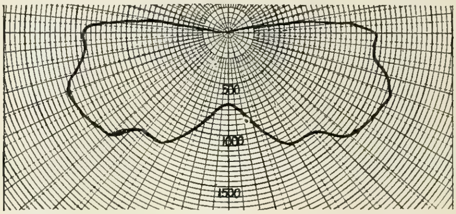


Fig. 9a.—Light distribution curve of a high pressure gas lamp with a clear globe. (Consumption 26.63 cu. ft; pressure 3 lbs.) Lamp is shown in Fig. 9.

Among the recent improvements in glassware has been the use of a small translucent quartz cylinder, closed at the base and fitting closely to the mantle. This cylinder will not break when subjected to extreme temperature conditions, such as plunging into cold water when at a temperature of 1,000° F. or higher. Its use has eliminated one of the difficulties of high pressure

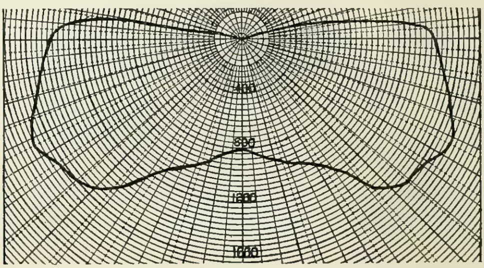


Fig. 10a.—Light distribution curve of a three-burner high pressure gas lamp with a clear globe. (Consumption 30.65 cu. ft.; pressure 2 lbs.) Lamp is shown in Fig. 10.

lamps, namely, of glassware breaking and also the need of an excessively large globe. In addition it has been rendered much more wind-proof. When used the temperature of the mantle is increased slightly and the additional radiant energy compensates for the higher absorption of translucent quartz.

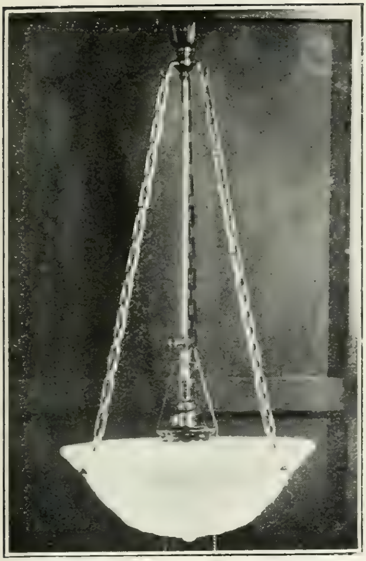
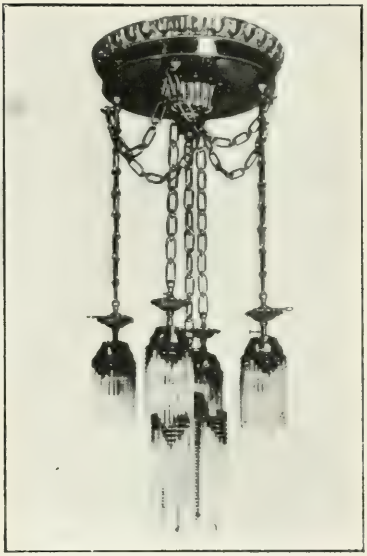
 

Fig. 11 (left)—Single burner semi-indirect lighting fixture; Fig. 12 (right)—Chain type direct lighting fixture.

Fig. 15.—Lighting of a post office sub-station in Philadelphia.

Fig. 13.—Deck window lighting of a men's furnishing store.

Fig. 14.—Semi-indirect store lighting.

The lamps are applicable to both indoor and outdoor lighting and especially for window lighting from the outside. For factory and shop lighting where the lamps can be placed well above the range of vision this type of gas lamp is excellent. In certain cases of shop lighting in very dirty places, the lamps can be successfully used without glassware, where insects do not prohibit.

Two types of high pressures lamps, together with the distribution curves of the light, are shown in Figs. 9 and 10.

LIGHTING FIXTURES AND APPLICABLE GLASSWARE.

The proper application of the various types of indoor lamps in obtaining artistic, efficient and pleasant illumination is an important consideration.

Artificial illuminants in general leave much to be desired in the distribution of light and invariably have too great an intrinsic brilliancy for bare exposure. The brightness of a normal low pressure inverted gas mantle is about 35 candle-power per square inch. While this is very much lower than the brightness of an electric filament (vacuum lamp 1,000 candle-power per sq. in.) it is still unpleasant and objectionable when in the direct line of vision, especially against a dark background. For this reason the use of shades, diffusing globes and reflectors is imperative.

INDIRECT AND SEMI-INDIRECT FIXTURES AND GLASSWARE.

With the present efficient construction of mantle burners and using one of the various automatic methods of ignition, it is possible to apply gas lighting to indirect and semi-indirect systems.

In the indirect system the light source is concealed from view and the illumination is obtained from the diffused reflection of the light-colored wall and ceiling surfaces. The effective light source is, therefore, in reality very large in area and of low intrinsic brilliancy, reducing eye fatigue. This method of illumination is necessarily less efficient than the direct or semi-indirect systems.

There have been some notable installations of this system of lighting, using gas as a light source, but by far the most common application is in the semi-indirect system.

In the semi-indirect system the light source is concealed from view usually by a dish shaped shade which transmits part of the light, approximately 30 to 40 per cent. plus absorption, and reflects the remainder to the ceiling or to a special receiving surface where it is diffused by the surface coating.

When the brightness of the shade is well proportioned so as to harmonize with the surroundings, this method of lighting is pleasing, comfortable, resting to the eyes and of quite high efficiency.

A very artistic and efficient semi-indirect fixture is shown in Fig. 11 and the distribution of light is shown in Fig. 11a. Of

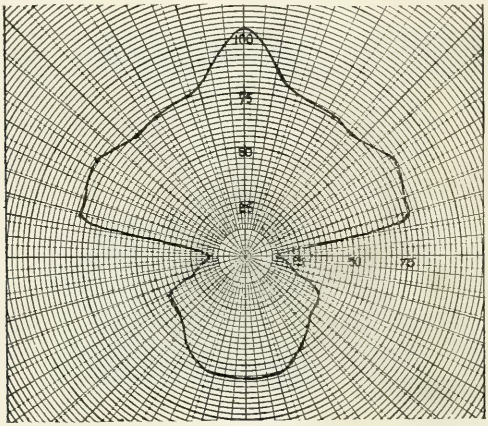


Fig. 11a.—Light distribution curve from a single burner gas lamp with a white glass bowl. (Consumption 3.62 cu. ft.; pressure 2.5 in.) Lamp is shown in Fig. 16.

the available light flux 65.9 per cent. is directed to the upper hemisphere and 34.1 per cent. to the lower. The total absorption of the fixture is approximately 21.5 per cent. A single inverted burner with clear cylinder is used.

DIRECT LIGHTING FIXTURES AND GLASSWARE.

There are available a large number of artistic, well made, direct lighting fixtures for both inverted and upright lamps. These fixtures, with their proper complement of glassware, are thoroughly pleasing to the eye. A typical chain type fixture for direct lighting is shown in Fig. 12. There are many other forms

and designs or artistic fixtures for both small inverted units and large single burner units.

The artistic effect is often a problem of personal taste and may involve an inefficient light source so far as illumination and economy are concerned.

In Fig. 8 is shown a large single burner fixture using an artistic leaded glass shade.

DESCRIPTIONS OF SUCCESSFUL GAS INSTALLATIONS.

An illuminant may have many virtues, such as efficiency, convenience, etc., but in order that these be appreciated it must be applied in the proper manner so as to be pleasing and comfortable to the eye and at the same time successfully accomplish the prime purpose of properly illuminating the desired objects.

Modern gas installations of various interiors, window lighting, etc., have embodied much ingenuity in the application of the fundamental principles of illuminating engineering.

In deck window lighting the panels in the ceiling are usually replaced by panels or ripple glass, although in some cases circular openings are made in the wooden panels and the edge of the reflector made flush with the lower face of the panel. When ripple glass is used the base of the reflectors are placed about 5 in. (12.7 cm.) from the panes. The units are located as close as possible to the front and side of the window nearest the observer.

An example of a well lighted window of a men's furnishing store is shown in Fig. 13. The window is approximately 8 feet (2.44 m.) wide, 7 feet (2.13 m.) high and 4 feet (1.22 m.) deep. Six single burner inverted lamps are used above the ripple glass. The intensity of illumination at the base varies from 10 to 15 foot-candles. Owing to the appreciable amount of light reflected above and slightly below the horizontal, the window at these parts is usually decorated so as not to attract the attention of the observers.

Fig. 14 shows a semi-indirect installation in a Trading Stamp Company. There are nine two-light fixtures spaced 15 feet (4.57 m.) apart, each fixture containing two small inverted burners around which semi-indirect glassware is placed.

Using a single mantle inverted burner on a consumption of

3.34 cu. ft. of mixed gas per hour this type of glassware showed 58.66 mean upper hemispherical candle-power, 38.0 mean lower hemispherical candle-power and 48.33 mean spherical candle-power. Of the total light flux available 60.7 per cent. is in the upper hemisphere and 39.3 per cent. in the lower. The absorption of the shade when clean is about 15 per cent.

Since the introduction of the high candle-power single burner inverted unit an additional large field has been opened for gas lighting business.

Fig. 15 shows a general view of a post office sub-station by these lamps, used in conjunction with the smaller type inverted lamps.[11] In meeting the exacting specifications required by the government for this important branch of lighting, gas has made a permanent and substantial step forward.

APPENDIX.

a. Mantle Igniter.

b. Telephos Filament Igniter.

c. Warren Magnet Valve.

d. Luther Pneumatic Valve.

e. Askania Lighter.

[11] Lee, James D., The Lighting of Post Office Sub-stations in Philadelphia; *Lighting Journal*, December, 1913, and January 1914.

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 8, 1914

PART II

Miscellaneous Notes

Council Notes.

A meeting of the Council was held in the general offices, 29 West 39th Street, New York, N. Y., November 12. Those present were: A. S. McAllister, president; E. M. Alger, C. O. Bond, H. Calvert, P. W. Cobb, C. A. B. Halvorson, Jr., Ward Harrison, George A. Hoadley, C. A. Littlefield, L. B. Marks, Preston S. Millar, Alten S. Miller, and J. Arnold Norcross. Mr. A. L. Powell was present as the representative of Mr. G. H. Stickney; Messrs. W. J. Serrill and A. Hertz upon invitation.

Mr. S. G. Hibben was appointed a director to fill the unexpired term of Mr. F. A. Vaughn, who resigned on account of his election to the vice-presidency.

Mr. Alten S. Miller was appointed a director to succeed Mr. V. R. Lansingh resigned.

The annual report of the Finance Committee of the preceding administration was read by Mr. C. A. Littlefield, chairman. The Council voted that the report, which was accompanied by a report on the accounts of the Society for the year ending September 30, 1914, prepared by a certified public accountant, be printed in the TRANSACTIONS, and directed that the following recommendations made by the committee be followed during the present year:

1st: That because of the general financial condition of the country, no extensive increase in appropriations be authorized for the coming year, and that all expenses be made on as conservative a basis as possible.

2nd: That following past practise each committee submit as speedily as possible, a budget of anticipated expenses during the year, this expense to be approved first by the Finance Committee and then authorized by the Council; that no committee be authorized to incur other expenses until the increased appropriation be first approved by the Finance Committee and then authorized by the Council. In other words, that each committee be held strictly within the budget appropriation during the next fiscal year.

3rd: That before any expense is authorized during the coming year, the Finance Committee be consulted and these additional payments have their approval before they are ratified by the Council.

Upon recommendation of the Finance Committee, the Council authorized the payment of vouchers Nos. 1867 to 1912 inclusive aggregating $1,504.60.

After considerable discussion of the desirability of recording stenographically the discussions contributed at Section meetings, it was resolved that the Council affirm previous instructions to the section boards of managers to secure transcripts of such discussions as may be of value for preservation in the TRANSACTIONS, and to limit the expense of transcription to a minimum.

Reports on section activities were received from Prof. G. A. Hoadley, vice-president of the Philadelphia Section; Mr. Ward Harrison, vice-president of the Pittsburgh Section; Mr. A. L. Powell, reporting for Mr. G H. Stickney, vice-president of the New York Section, and Mr. F. A. Vaughn, vice-president of the Chicago Section.

The following report was received from the Committee on Lighting Legislation:

The Committee on Lighting Legislation held a meeting on October 30, 1914, and considered the transcripts of laws relating to lighting now on the statute books of the following States: New York, Pennsylvania, and Connecticut. The transcript of the laws of New York and of Pennsylvania each covers an equivalent of about fifty typewritten pages, in which the references to lighting are with few exceptions very general in character. In many cases the regulations relating to lighting are included in sections of the law covering other topics such as ventilation, etc. The Committee now has in hand the preparation of a digest of these transcripts. The transcript of the laws relating to lighting in the State of Connecticut, covers only one typewritten page containing only very general requirements. It was decided not to proceed at this time with the plan to collate the lighting laws of other states with the possible exception of the comp

lation for Illinois, which is now under way. The Committee also considered the "General Orders" of the Industrial Commission of Wisconsin, which form the basis of the industrial lighting regulations of that state. These "General Orders" are subject to modification from time to time at the option of the Commission. The feasibility of formulating a model lighting law for adoption by various States was considered and for various reasons this proposal was thought impractical at the present time. However, as a step forward toward meeting the situation, it was decided to formulate a "Lighting Code" on school lighting and another on factory lighting. This work is now under way.

The Council voted that the Lighting Legislation Committee be instructed to continue along the lines stated in their report.

A communication from the New York Letter Carriers' Association was read. The latter organization asks for the co-operation of the Illuminating Engineering Society in an effort to eliminate glazed surface "window" envelopes from the mails on the ground that such envelopes are under many conditions of use injurious to the eyesight of postal clerks and carriers. Accompanying the letter was a package of 100 different envelopes of the type which the association desires to eliminate. A petition has been drafted by the Association urging the Washington postal authorities to prohibit this type of envelope and to suggest in its stead the use of similar envelopes without the tissue face. Envelopes of the latter type are now in rather extensive use. The Association desires to obtain from the I. E. S. technical information on the glare from the tissue-faced envelopes for the evident purpose of submitting it, along with the opinions of a number of prominent oculists, to support the petition and complaint to Post Office Department that such envelopes are impairing the eyesight and efficiency of postal employees.

It was voted that the foregoing matter be referred to the Committee on Glare for a report and recommendations from the illuminating engineering point of view, with special reference to the question of glare, to be submitted at the earliest convenient date.

Mr. W. J. Serrill gave a progress report for the Committee on Reciprocal Relations.

A written report of progress was submitted by Mr. G. H. Stickney, chairman of the Papers Committee.

The following additional committee appointments were confirmed:

Committee on Nomenclature and Standards: P. G. Nutting, W. A. Dorey, and W. E. Saunders.

Ligthing Legislation Committee: C. O. Bond.

Papers Committee: S. C. Rogers and Alexander Duane.

Sustaining Membership Committee: C. A. B. Halvorson, Jr., W. H. Rolinson, S. L. E. Rose, S. G. Hibben, E. B. Rowe, and G. S. Barrows.

Exhibition Booth Committee (Gas): Thos. W. Scofield.

School Lighting Committee: M. Luckiesh, chairman; F. Park Lewis, M. G. Lloyd, S. G. Hibben, R. B. Ely, C. A. Littlefield, C. E. Clewell, and F. K. Richtmyer.

Popular Lectures Committee: C. E. Clewell, chairman; W. S. Franklin, H. E. Ives, R. F. Pierce, A. J. Rowland, G. A. Sawin, G. C. Keech, chairman Sub-Committee on Industrial Lighting; A. L. Powell, chairman Sub-Committee on Store Lighting; E. R. Treverton, chairman Sub-Committee on Office Lighting; E. J. Edwards, chairman Sub-Committee on Residence Lighting.

Committee on Education: F. K. Richtmyer, chairman; Preston S. Millar, H. E. Clifford, A. E. Flowers, A. H. Ford, H. G. Hake, E. B. Rowe, C. F.

Scott, L. B. Spinney, A. N. Topping, W. E. Wickenden, and H. B. Dates.

Committee on Section Development: C. A. Littlefield, chairman; C. L. Law, O. L. Johnson, S. G. Hibben, S. C. Rogers, and L. B. Eichengreen.

Committee on Progress: F. E. Cady, chairman; T. J. Litle, T. W. Rolph, L. B. Marks, and P. W. Cobb.

Council Executive Committee: A. S. McAllister, chairman; L. B. Marks, C. A. Littlefield, J. Arnold Norcross, and Preston S. Millar.

Other appointments were made as follows:

Members of a joint *Committee* (of the I. E. S. and the American Ophthalmological Society) *on the Illumination of Test Types:* P. W. Cobb, chairman; P. G. Nutting and J. R. Cravath.

Representatives to the *United States National Committee* of the International Commission on Illumination: Louis Bell, J. R. Cravath, and Preston S. Millar.

Representative on the *American Institute of Electrical Engineers Standards Committee:* Clayton H. Sharp.

The appointment of a Committee on Heterochromatic Photometry was discussed at length and tabled for the next meeting.

Section Notes.

NEW ENGLAND SECTION

The next meeting of the New England Section will probably be held in the latter part of December or the early part of January.

CHICAGO SECTION

The Chicago Section held a joint meeting with the American Institute of Electrical Engineers and the Western Society of Engineers on Tuesday, November 24, 1914, in the Western Society of Engineers rooms, Monadnock Building. Mr. S. E. Doane, chief engineer of the National Electric Lamp Association, addressed the meeting on "Electric Light—A. Factor in Civilization." In his lecture Mr. Doane dealt with both the technical and commercial phases of illuminating engineering.

The tentative program of papers for the Chicago Section for the season 1914-1915 is as follows:

December—The Eye: Physiology of Sight. Psychology of Seeing.

January—Incandescent Light Sources (Gas and Electric).

February—Other Light Sources (Gas and Electric).

March—Decoration: Color Schemes; Fixture Forms; Use of Colored Sources.

April—Lighting of Small Interiors: Homes; Small Offices; Show Windows.

May—Lighting of Large Interiors: Churches; Halls; Large Offices.

June—Lighting of Open Air Spaces: Streets; Building Exteriors; Signs.

NEW YORK SECTION

A meeting of the New York Section was held Thursday evening, November 12, 1914, in the Engineering Societies Building. Dr. C. H. Sharp of the Electrical Testing Laboratories presented two papers: one entitled "Photometry of Gas-filled Incandescent Lamps," the other "Data on Commercial Daylight Lighting Equipments." The latter paper was accompanied by an exhibition of illuminants and color demonstrations. The usual informal dinner was held previous to the meeting at Keen's Chop House on 36th Street.

PHILADELPHIA SECTION

A meeting of the Philadelphia Section was held November 7, 1914, in the Engineers Club. A paper, "Physical Pho-

tometry," was presented by Dr. Herbert E. Ives and was discussed by Dr. Carl Herring and Mr. C. O. Bond. Sixty members and guests were present.

On Friday, November 20, 1914, the Philadelphia Section held a meeting at the Engineers Club. Two papers were presented: "Light as Utilized for Lighthouse Purposes," by Mr. Raymond Haskell, and "Lights and Lighthouses of the Delaware River and Coast," by Dr. Christopher S. Street. Navigation lanterns and lamps were exhibited. Eighty members and guests were present.

The following program for the rest of the season has been announced:

December 18—"Recent Developments in Gas Lighting" by T. J. Litle, Jr.; "New Methods and Devices in the Control and Distribution of Electric Lighting Installations" by Washington Devereux. Gas lamps and electrical control devices will be exhibited.

January 15—"Amusement Park Lighting—Lighting of Willow Grove Park" by Mr. Harry Markle; "Piping Houses for Gas Lighting" by H. H. Sterrett.

February 8—Joint meeting with American Institute of Electrical Engineers. "A Year's Progress in Illumination" by Prof. Geo. A. Hoadley; "Recent Developments and Applications of Incandescent Lamps" by Geo. H. Stickney. Electric lamps will be exhibited.

February 19—"Scientific Management" by Frederick W. Taylor. A demonstration of the pathescope, a new moving picture device, will be given.

March 19—"A Method of Securing Uniformity of Reading of the Flicker Photometer with Different Observers" by Herbert E. Ives and E. F. Kingsbury. Photometric apparatus will be exhibited.

April 16—"The Problem of Lighting Design." Methods used for designing: A. Direct Lighting. B. Indirect Lighting. Difficulties and faults in the use of such methods. Accuracy to be expected in the results accomplished. What constitutes good design. By Prof. Arthur J. Rowland. Exhibition of new types of lighting fixtures.

May 21—"Store Lighting" by W. R. Moulton. This meeting will be held in Baltimore, Md. The place will be announced later.

PITTSBURGH SECTION

A meeting of the Pittsburgh Section was held November 20 in Pittsburgh. A paper, "The Lighting Requirements of Street Cars" by Mr. L. C. Doane, was presented.

The following tentative program has been announced:

December—"Modern Units for Street Lighting."

January—A joint meeting with several engineering societies, and a popular lecture and demonstration of school lighting and optical hygiene. This meeting will be held in Cleveland, O. The date will be announced later.

February—To be announced later.

March—Joint meeting with the American Institute of Electrical Engineers. Paper: "Headlights and Projections" or "Modern Lamp Manufacture."

New Members

The following applicants were elected members of the Society at a Council meeting held November 12:

ALLAN, THOS. G.
District Representative, United Gas Improvement Company, 4236 Main Street, Philadelphia, Pa.

ATKINS, DAVID F.
Acting Chief Engineer Light and Power, Department of Water Supply, Gas and Electricity, Municipal Building, New York, N. Y.

Cousins, George C.
Illuminating Engineer, Hydro-Electric Power Commission of Ontario, Strachan Avenue, Toronto, Canada.

Dobson, W. P.
Engineer in charge of laboratories, Hydro-Electric Power Commission of Ontario, Strachan Avenue, Toronto, Canada.

Drummond, C. H.
Illuminating Engineer, Philadelphia Electric Co., 1000 Chestnut Street, Philadelphia, Pa.

Myers, R. E.
Chief Engineer, Westinghouse Lamp Company, Bloomfield, N. J.

Westervelt, H. P.
Illuminating Engineer, The New York Edison Company, Irving Place and 15th Street, New York, N. Y.

Personal.

Following are biographical sketches of Dr. A. S. McAllister, president, and Mr. C. A. Littlefield, general secretary of the Illuminating Engineering Society for the year 1913-1914.

Dr. A. S. McAllister was born at Covington, Va., February 24, 1875. After attending the public schools of that place, he entered the Pennsylvania State College where he received, in 1898, the degree of B. S. and subsequently the degree of E. E. From July, 1898, to August, 1899, he was connected with the Berwind-White Coal Mining Company at Windber, Pa., devoting his time to electric lighting and electric locomotive operation and repair. The following year he spent in the factory of the Westinghouse Electric & Manufacturing Company studying the manufacturing details of direct current and alternating current machinery. He took a post-graduate course at Cornell University in physics and electrical engineering and received the degree of M. M. E. in 1901. Four years later he received the degree of doctor of philosophy. From 1901 to 1904 he was an assistant and instructor in physics and applied electricity at that institution. In 1904 he became acting assistant professor of electrical engineering. In 1905 he became associate editor of the *Electrical World* of which journal he is now editor-in-chief. Since 1909 he has been professorial lecturer on electrical engineering at the Pennsylvania State College. Dr. McAllister is the author of a book entitled "Alternating-Current Motors" (1906); chapters on "Transformers" and "Motors" in the "Standard Handbook for Electrical Engineers," and has received several patents for alternating-current machinery. He has also contributed many articles on engineering subjects to the technical press and the transactions of scientific and commercial organizations. Prior to his election to the presidency, he had been a director for three years and an active member of several committees of the Illuminating Engineering Society. Dr. McAllister is a fellow of the American Institute of Electrical Engineers, and a member of the American Association for the Advancement of Science, the American Electro-chemical Society, the National Electric Light Association, the New York Electrical Society, the Society for the Promotion of Engineering Education, the Illuminating Engineering Society, the Sigma Xi, Phi Kappa Phi, and Eta Kappa Nu fraternities and a number of prominent social clubs and organizations.

Mr. C. A. Littlefield was born in Philadelphia, Pa., but his early life was spent in Jacksonville, Fla. After living

A. S. McALLISTER, President.

C. A. LITTLEFIELD, General Secretary.

there a number of years he came north, settling in Morristown, N. J., and was later graduated from the Morristown High School. A year or so after graduation he came to New York, connecting himself with the office of a civil and sanitary engineer. He left this position May 1, 1891, to enter the service of the then Edison Electric Illuminating Company of New York, the predecessor of The New York Edison Company. He was connected first with the underground department, but about six or eight months after coming to the company, he was transferred to the inspection department, and has been connected with that department since, occupying during these years various positions. At that time the historic old Pearl Street station was in operation and much of his work required him to be at this station, but, of course, this did not last long as the station was abandoned shortly afterward. Mr. Littlefield is a charter member of the Illuminating Engineering Society and has been active in various committee work in this Society since its organization. He was a manager of the New York Section in 1909 and 1910; and was elected a director of the Society in 1912. He resigned as a director in October, 1914, to accept the office of general secretary. He is a Class B member of the National Electric Light Association, having joined in 1905, and at present is secretary of the Commercial Section. He is also a member of the Jovian Order, the National District Heating Association, the Electric Vehicle Association of America, the American Museum of Safety as well as several other civic and national organizations.

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SELF-CONTAINED PORTABLE ELECTRIC LAMPS FOR MINERS.*

BY H. H. CLARK.

Synopsis: This paper sketches briefly the history of mine illumination and describes some of the primitive methods used to produce light in the early days of coal mining. Reference is made to the first attempts to make portable electric mine lamps and the lamps now used are described in detail. The author describes the activities of the United States Bureau of Mines in connection with the development of portable electric lamps and outlines the requirements which lamps must pass in order to receive the approval of the bureau. The paper closes with a brief discussion of the probable tendency of future portable electric lamp development.

From the earliest days of coal mining the miner's lamp has been associated with some of the saddest underground tragedies. During the hundreds of years that have elapsed since the first British miner carried his excavations beyond a point where the sun afforded enough light for his work, the miner's lamp has assumed many forms and has been studied by many men. The difficulty of this problem is evidenced by the fact that to-day more types of lamps exist than ever before and more men than ever before are studying the problem of mine lighting.

A coal mine covers a large area in which the centers of activity are constantly changing as new working places are opened and old working places are abandoned. It is actually necessary to illuminate at one time only a small proportion of the workings, and yet a man must never be without light. Therefore, it is not

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

expedient to light a mine as a street is lighted by the use of a few fixed lamps; the workmen must carry their lamps with them. Were it not for the fact that explosive gases are sometimes encountered in coal mines, the problem of providing suitable lamps would not have been a serious one and probably would never have been given the profound attention that, lasting for several centuries, has finally given rise to the development of portable electric lamps for the use of the individual miner.

The history of mine lighting is filled with descriptions of curious means that were employed years ago for producing light. Some of these are so unusual that I will mention them briefly with due acknowledgment to Prof. E. N. Zern for references taken from his "History of Mine Lighting" which appeared serially in the *Coal and Coke Operator* beginning in the January, 1912, issue.

Coal was dug in Great Britain as early as the first part of the 13th Century, and after the diggers had penetrated the seam for a certain distance inflammable gas was encountered. At first the miner did not clearly understand what produced the resulting explosions, but they were finally related to the torches and open flames that were used to illuminate the underground working places and immediately the men cast about to provide substitutes for these methods of producing light. Among the substitutes that were tried were the faintly phosphorescent scales of dried fish skins, a mixture of flour and lime, and fireflies imprisoned in a bottle. As may be imagined, these sources of light were too feeble to allow the men to work efficiently and because of the faintness of the illumination gave rise to dangers that were nearly, if not quite, as serious as the ignition of gas. Failing for the moment to find a satisfactory substitute for the open flame, the miners attempted to test for the presence of gas and to dissipate it when it was found. It is recorded that in certain mines a dog was lowered down the shaft on a rope and when his howls indicated that he had encountered a body of fire damp he was pulled up and a bush was attached to the rope and rapidly raised and lowered in the shaft for the purpose of dissipating the gas.

In certain English mines a man was employed to go down into

the mine each day in advance of the regular workers. This man was provided with an open torch and with an all-enveloping garment made of leather or some heavy fabric. It was his duty to visit all places where gas might accumulate, to crawl into these places on his hands and knees, and to raise his torch until any gas that might be present had become ignited. After he had visited every part of the mine and burned off the collections of gas it was considered safe for the men to enter and carry on a day's work.

Another method for gas dissipation was to burn at gassy points in mines lamps that were kept flaming night and day the year round, thus igniting the escaping gas before it could accumulate in large quantities. In those days the mines were unventilated, and the means just described for removing the inflammable gas charged the air with poisonous gases and thus this produced a condition that detracted from the merit of the method as a safety measure.

The next important attempt to provide a substitute for the open flame was the development of the "steel mill," which consisted of a small disk of steel revolved by a train of gears operated by hand. While the mill was driven at high speed a flint was held against the periphery and the light produced by the resulting train of sparks was used as a means of illuminating the working places of many mines. It is hard to believe that the steel mill was greatly superior to the firefly or the fish scales, and yet Prof. Zern states that for at least fifty years the steel mill was much used as a source of light in gaseous mines.

It is on record that attempts were made to reflect sun light down mine shafts and into the workings, but for obvious reasons the result was not a success.

About one hundred years ago the Davy lamp appeared and since that date lamps based on the Davy principle have been the standard means of lighting gassy places in coal mines.

So far as I am aware the first portable electric mine lamp was used in an English colliery. William Maurice in a lecture delivered at the University College, Nottingham, March 15, 1913, stated that the first attempt to adapt the incandescent lamp to mine illumination was made in 1881 in a Nottinghamshire colliery

in England. The first portable or semi-portable lamp was exhibited in 1882. This lamp was operated from storage batteries weighing 9½ pounds (4.31 kg.). Another portable electric lamp was exhibited in 1885. This lamp was operated by seven storage cells weighing 8 pounds and gave 2.5 candle-power for 10 hours. Mr. Maurice also reports that in 1887 600 lamps were in use in a South Wales colliery. In 1897 500 lamps were in regular use in an English colliery as substitutes for flame lamps. One hundred more were added in 1898, and by the latter part of 1899, 1,000 were in daily use.

So far as I know there has never been published an authentic history of the development of the portable electric mine lamp in this country. Many men have been engaged independently in this work, and to mention any one or even several names would not be fair to many others who have devoted a great deal of time and attention to improving the design and construction of this lamp. The development in this country has covered so long a period that it would be hard to give a definite date on which the actual use of lamps in coal mining operations began, but it is safe to say that they have been used regularly in some mines for at least five years.

In the past two years the development has been very rapid and at the present time has reached a stage where it looks as if the general adoption of electric lamps, especially in mines where safety lamps are required, might be looked for in a comparatively few years.

Electric mine lamps may be divided into two classes: those that are carried in the hand and those that are worn in the cap. Both are used in this country, although the preference seems to be for the cap lamp. The hand lamp only is used in Europe.

Lamp equipments consist of a battery, a lamp mounting, and means of connecting the two electrically. Most lamps use storage cells, although I believe that some primary battery lamps are in the course of development. Usually a single lead cell or two alkaline cells are used. The cells are enclosed in metallic casings usually of steel or aluminum. Hand lamps are usually designed with the bulb mounted on the top or side of the metallic casing that contains the battery. One of the most useful designs for

coal mine service is the so-called "lighthouse type" in which the bulb is mounted in a vertical position on top of the battery casing, surrounded by a glass dome, and further protected by three or four steel pillars that support, over the top of the dome, a steel disk or cap to which the carrying hook is attached. These lamps can be made very sturdy and durable. The capacity of the batteries is from 10 to 12 ampere-hours, and the average mean lower hemispherical candle-power is about 0.80. The lamp weighs about 5 pounds (2.26 kg.).

The batteries used with cap lamps are usually not so heavy as hand lamp batteries and have somewhat less capacity, but are quite rugged in construction and strongly encased. The bulb is mounted in a headpiece (or reflector) designed to be attached to the miner's cap. This headpiece is provided with a reflector which sends out a restricted light stream that follows quite closely the movements of the wearer's eyes.

Both types of lamp are subjected to severe treatment when in use. In general, hand lamp service is likely to be more severe than cap lamp service, because lamps that are carried in the hand or frequently set down or hung up are likely to get more falls and hard knocks than a lamp that is worn attached to a man's body. On the other hand, the design of the hand lamp lends itself better than the design of the cap lamp to simple rugged construction. Hand lamps can be made very compact, while cap lamps must use a comparatively frail cord for connecting the two principal parts of the outfit.

The ideal lamp must be free from possibility of gas ignition, must give for the proper period enough light properly distributed, must be reasonably light in weight and shaped so that it may be carried easily, must not spill or leak electrolyte, must be capable of giving uninterrupted service, and must have a reasonably low cost of maintenance.

The Bureau of Mines first undertook its investigations in the latter part of 1912. The work was undertaken because the Bureau believed that the adoption of electric lamps would make for safety not only in mines where the danger of gas ignition exists, but also in mines where open flame lamps are used.

because the open flame presents a certain fire risk that the use of electric lamps eliminates.

In order to promote the adoption of electric lamps the Bureau worked first to establish their safety under all conditions of mining and second to assist in the development of a practical lamp that the Bureau could unhesitatingly recommend as a satisfactory substitute for less safe lamps. The first step was to find out whether or not there was any way in which these lamps could ignite explosive gas.

After an exhaustive series of tests it was decided that few if any of the batteries used for portable lamps could give off sparks sufficient to ignite gas, but that any bulbs that gave a reasonable amount of light would ignite gas if the bulbs were broken so that the filaments were not injured. The Bureau's recommendations for safety have been based on the results of these experiments. The Bureau's first work was to test a number of such lamps as were provided with safety features that made it impossible for them to ignite gas. These safety features consisted in devices that cut off the current from the bulb when it was broken or that short-circuited the battery so that the filament could not glow even if it were uninjured.

The results of these tests assured the Bureau that the lamps examined were perfectly safe and they were approved for safety only. While these tests were going on the Bureau was investigating the general subject and outlining a list of requirements having an indirect bearing on safety which, in the Bureau's opinion, should be fulfilled by a practical electric lamp.

When safety is assured the next requisite of a lamp is light producing capacity, and for mining service a lamp should have the capacity to burn uninterruptedly and with undimmed brilliancy for a certain number of hours of every day in the year.

The cost of operation and maintenance of the lamp must not be so high that it is out of proportion to the value of the service given by the lamp as compared to the value of the service given by other lamps. In addition to the qualities just mentioned there must be no leaking or spilling of electrolyte from the battery while in use.

The weight of the lamps is also important. The battery and

the rest of the equipment must not be made so heavy that it becomes a burden to the user or hampers his movements. But the decision as to the proper weight of a lamp is so largely affected by personal considerations that the Bureau did not concern itself with this phase of the lamp problem.

In connection with the light giving capacity there must be considered not only the flux of light, the intensity of light, the distribution of light, and the time that the lamp will burn on one charge of battery, but also the capacity of the lamp to repeat its light giving performance without serious interruptions of service. Thus the determination of the light giving capacity of a lamp involves not only photometric measurements but observations as to the reliability of the various parts of the equipment.

The cost of maintenance will vary with the conditions of service and the care and attention that the lamps receive, but one of the principal items of expense will be bulb renewals. The life of the bulbs is therefore an important matter. And from the point of service it is equally important that the candle-power and current consumption of the bulbs should be uniform.

The first step in determining the light giving capacity of the lamps was to fix standards of light flux, intensity, and distribution, and a minimum time-of-burning per charge of battery.

The minimum values for light flux and intensity were determined by reference to the flux and intensity of a good safety lamp and were thus fixed for hand lamps at 3.0 lumens and 0.4 candle-power, respectively, and for cap lamps at 1.5 lumens and 0.4 candle-power. In each case the candle-power is the mean over the stream of light projected by the lamp.

The distinction made between hand lamps and cap lamps as to flux of light was based upon the intention to require the same amount of effective illumination from each class of lamps. It is quite manifest that a cap lamp with its restricted stream of light which follows the movements of the wearer's head can produce with half the flux the same amount of effective illumination as a hand lamp whose light stream had twice the area of the cap lamp light stream. These requirements for flux and intensity are low, but not so low as they would appear at first glance, since the lamps must give this amount of light at the end

of 12 hours at any time during the life of the bulbs. This will insure that when the battery is freshly charged and the bulbs are new the amount of light will be considerably greater than the Bureau's limits.

The distribution of light is an important matter which has received little attention until recently. It is surprising what satisfactory illumination for mining purposes can be obtained from sources of small candle-power carried in the user's cap, provided that the light is distributed uniformly over the illuminated surface.

The Bureau prescribes that the distribution of light from lamps that use reflectors shall be determined both by observation and by photometric measurement.

The observation test is described as follows: The lamp shall be placed 20 inches (50.8 cm.) away from a plane surface that is perpendicular to the axis of the light stream of the lamp. When so placed the lamp shall illuminate a circular area not less than 7 feet (2.13 m.) in diameter. All observations and measurements of distribution shall be referred to this 7-foot (2.13 m.) circle, regardless of how large an area the lamp may illuminate.

As observed with the eye there shall be no "black spots" within the 7-foot circle nor any sharply contrasting areas of bright and faint illumination anywhere.

The dimensions 20 inches (50.8 cm.) and 7 feet (2.13 m.) are merely arbitrary values that define a cone of light having a solid angle of 130 degrees which is the angle selected by the Bureau as the minimum for cap lamps. This angle is so large that a man is scarcely conscious of the shadows that surround him.

The requirements for distribution as determined by photometric measurements are described as follows: The average illumination (in foot-candles) on the best illuminated one tenth of the diameter shall be not more than twice the average illumination throughout the diameter, and for at least 50 per cent. of the diameter the illumination shall be not less than the average.

The requirements for the distribution of light as measured by a photometer are subject to a reasonable amount of stretching if the distribution as observed by the eye is perfectly satisfactory.

Twelve hours was selected as the proper time of burning per charge of battery. This does not mean that the lamp should burn just that length of time. It may burn longer than this; or if it is capable of producing for 12 hours the minimum amount of light prescribed by the Bureau, anyone using the lamp may, of course, use a larger bulb and obtain more light for a shorter time if such performance is satisfactory to him.

The greatest item of expense connected with the operation of the lamps will be the cost of bulb renewals; consequently the Bureau has placed in its specification a requirement for the length of life of lamp bulbs. The reports that came from abroad regarding the life of foreign lamp bulbs when used with portable electric mine lamps indicated that from 600 to 1,000 hours life are to be expected. The Bureau's experience at the time these specifications were undertaken led us to believe that American bulbs could not give this life. The bulb manufacturers were interviewed and they promised their co-operation in obtaining bulbs that would give 300 hours life when used with primary batteries and acid storage batteries, and 200 hours when used with alkaline storage batteries, which was about the limit that they felt could be reached in the present state of the art. At the same time the Bureau established requirements for the uniformity in energy consumption and candle-power of bulbs that, if met, will probably help to bring up the life of the bulbs by improving their quality in general. While these developments were going on the Bureau made tests of commercial bulbs made in this country that, while burning at a satisfactory efficiency, gave an average life of 870 hours. Eighteen per cent. of the bulbs operated for more than 1,600 hours. These results were obtained from bulbs that operated on lead storage cells.

The Bureau embodied its requirements in Schedule 6 and is now engaged in examining lamps submitted under the provisions of that schedule. Lamps that pass the Bureau's tests receive the formal approval of the Bureau.

The tendency of portable electric lamp development will probably be to simplify and strengthen the construction of the equipments, and to facilitate their repair. Much work will have to be done on the standardization of bulbs.

There will probably be a tendency to increase the light giving capacity of the equipments as soon as improvements in battery capacity and bulb efficiency will allow of such an increase without adding weight to the equipment.

The prospects of the portable electric mine lamp seem very bright from either a technical or a commercial point of view. And this last step in centuries of development bids fair to be the solution of the mine lighting problem.

DISCUSSION.

MR. H. O. SWOBODA (Communicated): Mr. Clark points out, that the first portable electric mine lamps were used as long as thirty years ago and that their *weights* ranged from 8 to 9½ pounds. It is safe to say that this excessive weight prevented the general introduction of these lamps and matters rested pretty well until 1912. At that time the carbon filament lamps were replaced by tungsten lamps. Due to their high economy in energy consumption, it was possible to reduce the capacity and consequently the weight of the storage batteries to such an extent that the self-contained portable electric lamps have come within the possibility of a commercial success.

At first glance it appears to be strange, that in Europe hand lamps only are employed, whereas in this country cap lamps are preferred by far. The reason is, that the European miner in most cases is obliged to perform his work lying down flat or bent down and very often he has to crawl to his working place, because the coal veins are very small. Under these conditions cap lamps would not be possible, because they would not throw the light in the proper direction and the flexible cable, connecting the lamp and the battery would not stand such rough usage very long. Hand lamps on the other hand, being more rugged, will withstand this rough treatment and once placed, will throw the light in the direction of the working place and will not be interfered with by the miner's movements. In this country there are so many large coal veins that it does not pay to remove the coal from the small veins for the time being. The miner can therefore perform his work standing upright and can use a cap lamp very conveniently. I presume, that in the course of time, both

types of lamps will be used side by side in Europe as well as in this country, that type receiving the preference which is the most suitable for the local conditions existing at the mine and for the class of work which the miner has to perform.

I also would like to add a few words regarding the expense connected with the operation of the lamps. The Prussian Bergassessor Schorig reports at the twelfth General Miners Day at Breslau, Germany, in 1913, that the number of either poorly or not burning hand lamps, returned from the mine "Hermann"[1] at the end of each shift was:

In October, 1912	1.82 per cent.
In November, 1912	1.65 per cent.
In December, 1912	1.43 per cent.
In August, 1913	1.25 per cent.

being an average of 1.5 per cent. for the four months.

The same experience has been collected by the Bullcroft Main Colliery Company, Ltd., Doncaster,[2] England, the defects caused by the incandescent lamps proper being about 1.0 per cent. and by the storage batteries about 0.5 per cent. In the Kalimines "Frischglucck" and "Desdemona," both in Germany, the total percentage of defective lamps is reported to be as low as 0.5 and 0.7, these low figures being attributed to the better treatment which the lamps receive in Kalimines.

MR. GEO. SCHLUEDERBERG (Communicated): The Pittsburgh Coal Company is using in its mines some 2,500 of these lamps and expects to add 10,000 more lamps. The head-light lamps are preferred as the miners object to working with the hand lamp, claiming that it is not as convenient as the cap lamp.

The results being obtained from the lamps in use are rather satisfactory as far as the lighting effect is concerned; some few minor troubles with cords and batteries are being experienced, but these are gradually being overcome as the men become familiar with the lamps, and experience teaches what little changes and betterments can be made.

Although rather satisfactory results are being obtained from the two types of lamps now in use, the company is proceeding rather slowly in installing others, as additional information is

[1] The mine "Hermann" uses 4,000 hand lamps equipped with lead batteries (Ceag lamps).

[2] This company operates more than 10,000 lamps of the same type.

expected from the Bureau of Mines which is making tests and will likely pass other lamps as safe to use, in addition to those that have now been passed.

From personal observation I am rather well satisfied with the results obtained from these lamps thus far, but I am hoping for much more and many improvements and betterments.

It is quite a relief to those in charge of the operation of the mines to know that there is a lamp that is safe for our gaseous mines, acceptable to the miner, and capable of giving him nearly as good results as did the open light, to which he had become much attached.

Mr. G. H. Stickney: There is a very real need of bettering lighting conditions in mines. The prevention of accidents, the preservation of eyesight and efficiency of labor, all demand better lighting.

Mine lighting has always presented difficult problems, but recent activity, both from the standpoint of increased efficiency of operation and the betterment of the working conditions, is attracting considerable attention to the subject. This is likely to result in greater progress in the near future.

The miner's portable incandescent lamp presents a particularly hard problem, on account of the narrow limitations in which it is necessary to work. Since the battery must be carried around by the working miner, it must necessarily be as light in weight as practicable; therefore, the lamps must be of low power consumption and highly efficient in order to supply a reasonable amount of light.

Lamps used in this service are of very low voltage and, therefore, subject to relatively high loss by conduction of heat from the filament by the leading-in wires. Moreover, the filaments being very short, a very slight variation in length makes a high percentage of variation in resistance of filament, so that it is difficult to produce accurately uniform lamps.

In view of these features, the low voltage lamp is at considerable disadvantage as compared with the 110 volt type. However, the recent improvements in incandescent lamps have greatly enlarged the possibilities of these miner's lamps, so that they will be of great benefit in the safe operation of mines, even though it

may not be possible to realize some of the ideals secured in ordinary classes of lighting.

MR. ROBERT P. BURROWS: I believe that Mr. Clark should be highly complimented upon the work which he has done to bring about the present high standard of electric mine lamp outfits. Through his efforts I believe that illuminating engineers will, or should, give more of their attention to this subject than they have during the past 5 years.

The Bureau of Mines specifications require an angle of 130 deg. for the light stream. At first thought it seems as if this was rather a large angle for the small wattage lamp used and that not much light would be obtained where it was needed. But the fact that no other illumination is available in a great majority of underground workings would make it difficult for anyone to move freely and safely through the passageways unless his lamp had such a wide angle of light. The question then resolves itself into one of distributing this light to the best advantage.

We might divide the miners into two classes—those who break up the coal and load it on the cars and the machine runners who cut the coal, the shot-firers and the men who do the drilling. The former class need a more uniform distribution of light; while the latter need the wide angle of light for free movement, yet it would seem that they also need a beam more concentrated than the first class so that they can get a good deal of light on the particular machine with which they are working.

Another point which should be considered is the life of the incandescent lamps. I do not believe that this question has been considered from the angle of economy of light production. At first thought it would seem that the cost of light production for such a small outfit taking such a small amount of current would not be very great, and it would seem that as the coal does not cost the miner a great deal and that the incandescent lamps require rather frequent renewal, that they should have a long life. But when we consider the other factors, such as interest on investment, repairs, renewals, cost of current, and, largest of all, depreciation of the outfit, then this economy of light production assumes larger proportions.

In this connection the weight of the outfit must be considered and it must be remembered that an increase in lamp life would mean a decrease in efficiency of the lamp so that for a predetermined amount of illumination the weight of the battery would have to be increased. I have in mind a case where increasing the lamp life from 300 to 1,000 hours would increase the weight and cost of the battery approximately 40 per cent. It seems to me that the battery plate renewals will cost as much as, or more than, the bulb renewals.

THE LOCOMOTIVE HEADLIGHT.*

BY J. L. MINICK.

Synopsis: A number of states have recently passed laws specifying the light requirements for locomotive headlights, almost all of which virtually exclude all classes of light sources except the electric arc light. Apparently little thought was given, in the framing of these laws, to the possible dangers accompanying the use of high intensities in the light beam. A number of tests have been conducted from time to time to determine the dangerous conditions that may arise from the use of various classes of light sources in headlight service. These test data, so far as they are available, have been collected, compared and analyzed and such points as have been well established are presented in this paper in terms as nearly comparable as possible. Formulas have been developed and are presented wherever the data available seem to warrant doing so, and conclusions are arrived at by the use of methods differing from those employed in various test reports. The results show that the conclusions and recommendations of the American Railway Master Mechanics Association are entirely correct if carried out within the limits given in this paper.

The locomotive headlight has been receiving considerable attention for several years past, largely along legislative lines. So far about thirty States have passed laws[1] requiring the use of headlights of comparatively high candle-powers so that, regardless of whether the standards fixed by law are warranted, or whether or not the requirements have been properly stated, it is evident that there is a strong desire for a change from present standards. If this desire could be reduced to concrete facts, it would probably be found that instead of desiring a headlight of higher candle-power, the enginemen actually want one which, when once put in good operating condition, will remain in that condition for some length of time.

It is a very difficult matter to maintain an oil lighted headlight in good working condition constantly. The height of the flame will vary with draught conditions, which in turn are dependent upon the speed of the train, the velocity and direction of wind, temperature, etc. The quality of the oil plays an important part;

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

so also does the trimming of the wick. Excessive heat causes rapid oxidation of the surface of the reflector. This can be removed only by frequent polishing, which in turn scratches, and eventually destroys the reflecting surface.

There are a number of variable factors entering into the make-up of a completed headlight, as for instance, the diameter, depth and focal length of the reflector, the size, shape and candle-power of the light source, the color value of the light source, the reflecting value of the reflector, the transmission of the glass, etc. It is obvious that reference to only one of these many variable factors does not by any means fix the value of the headlight. Neither does reference to only the distance at which an object can be seen, fix its value.

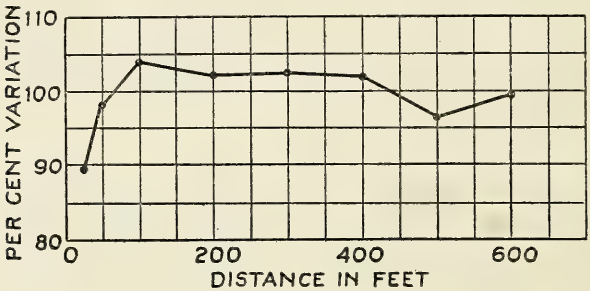

Fig. 1.

It has been suggested that the most satisfactory method of expressing the value of a headlight, is to refer to the candle-power and angular spread of the projected beam. In using this method, however, there are two uncertainties that must not be overlooked. It has not yet been determined definitely that the law of inverse squares holds true for the beam of light (approximately parallel rays) projected by a parabolic reflector or a semaphore lens. Neither has it been determined what distances from the headlight give the most representative readings for calculating the candle-power of the projected beam.

Fig. 1 shows the result of the testing[2] of four 10-inch semaphore type lens headlights (6-inch (15.24 cm.) focal length) equipped with 6-inch (15.24 cm.) prismatic glass reflectors (3-inch (7.62 cm.) focal length) and one 18-inch (45.72 cm.) by

8½-inch (21.6 cm.) parabolic metal reflector headlight (2¾-inch (6.98 cm.) focal length) to determine to what extent the law of inverse squares holds true. These headlights varied in average projected center beam candle-power fom 3,442 to 46,000 and in angular spread of beam from about 2° to 7°, the wider angles of spread being for the lower beam candle-powers. The average projected, or apparent beam candle-power as it has been termed, was fixed at 100 per cent. for each of the headlights tested. The per cent. variation from the average was then determined for each headlight at each reading station. The variations, plus and minus, were then summed up and gave the curve shown. With but one exception the variation for each of the reading stations is well within 5 per cent. above and below the average. The one exception is due to one extremely low reading at the 25 foot station. All the other individual readings at this station are very close to 95 per cent., so that if the headlights tested can be taken as being representative of headlights in general, these tests indicate that the law of inverse squares holds within a reasonable degree of accuracy and that readings may be taken at almost any convenient distance, though below 50 feet (15.24 m.) there is probably a greater chance of error than at other points.

About a year ago the American Railway Master Mechanics Association canvassed the railroads represented by their membership, to ascertain the order of importance of the functions of a locomotive headlight.[3] The replies received represented about 30,000 headlights. A summary of the canvass, both on the basis of headlights represented and number of replies received, shows the following order of importance:

1. To warn the public and employees of the approach of a train. (By projecting the beam along the track, thus attracting the attention of persons on the track and warning them of the approach of danger.)
2. To enable the engineman to observe such wayside objects and landmarks as whistle posts, crossings, cattle guards, buildings, etc. (Thus enabling him to gauge the speed of his train and maintain his schedule.)
3. To serve as a marker to designate the head end of a train. (Both ends of a train must be protected at night by distinc-

tive light signals. The size, shape, color, intensity and mounting height of headlight are peculiar to this light only.)

4. To display locomotive or train numbers. (These numbers are necessary for the despatching of trains. They are usually displayed in the sides of the headlight case and are illuminated at night through slots cut in the reflector.)
5. To enable the engineman to see an object on the track at a sufficient distance ahead of his train to permit stopping in time to avoid an accident.

The functions recited above may be said to be positive in character, *i. e.,* so far as they only are concerned, there need be no maximum limit set for the apparent beam candle-power, except that point beyond which additional light does not assist in the protection of the public or in the operation of train service. There are however, several conditions of a negative character that must be seriously considered in selecting a headlight:

1. The intrinsic brilliancy of the beam of projected light must not be high enough to temporarily blind persons and animals on the track, thus causing them to hesitate in moving off the track or to step to another track on which an unnoticed train is approaching.
2. The apparent beam candle-power must not be high enough to blot out colored signals such as classification lights, burning fusees, red lanterns, etc.
3. The apparent beam candle-power must not be high enough or of such color value as to cause a distortion of the color or an apparent shifting of the position of semaphore, switch and other fixed colored signals.

FIRST FUNCTION.

In order to warn the public and employees of the approach of a train, the apparent beam candle-power of a headlight must be high enough to be seen at a considerable distance and yet so low that the intrinsic brilliancy of the beam will not temporarily blind persons and animals on the track.

Range of Projected Beam.—Fig. 2 shows the approximate distance at which a beam of approximately parallel rays of white light may be seen in both rainy and clear weather, by persons in line with the axis of the beam and looking towards the source of light. The curves are plotted from the formulas,

$$\text{Distance in miles} = 1.09\sqrt{\text{Apparent beam candle-power}} \text{ (for rainy weather,)}$$

$$\text{Distance in miles} = 1.53\sqrt{\text{Apparent beam candle-power}} \text{ (for clear weather,)}$$

developed by the German Light House Board at Hamburg.[4] As an example, a beam of 3,000 apparent candle-power can be seen at a distance of approximately 60 miles (96.56 km.) in rainy weather and slightly over 80 miles (128.75 km.) in clear weather. It is evident from this that the maximum value of the apparent beam candle-power can safely be placed at not over 3,000. Any higher value would be of no value as the light could serve no useful purpose.

The usefulness of the beam of light projected by a headlight is largely dependent upon whether the local contours of the

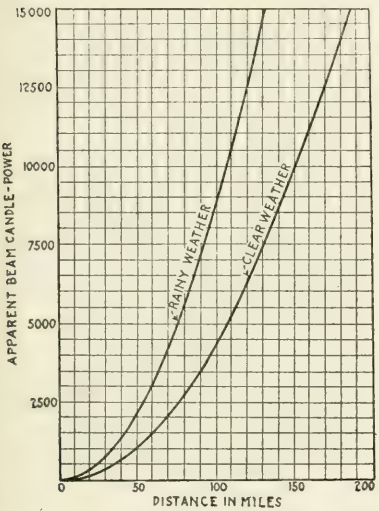

Fig. 2.

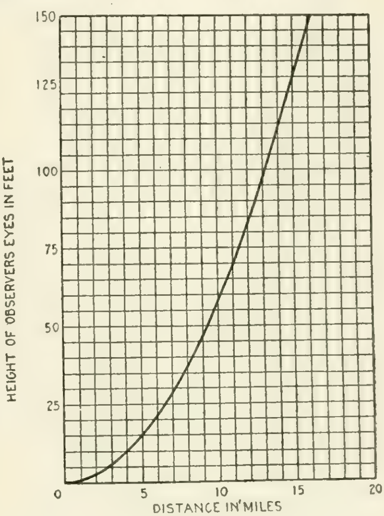

Fig. 3.

earth's surface are such as to permit the beam being seen at the maximum distance. In the East where railroads generally follow the course of streams in order to pierce the mountain districts at reasonable grades, the tracks are seldom straight and the beam looses its usefulness. In the West across the great plains, the track can be laid straight, but the curvature of the surface approaches closely the true curvature of the earth. Fig. 3 shows the distance at which objects of various heights can be seen where the curvature of the surface is true, as at sea, the observers eye being tangent with the surface.[5] As an example, the average height of the headlight above the rail is about 10

feet (3.05 m.). If the observers eye be placed at the focal center of the headlight, the horizon will be at a distance of 4.18 miles (6.73 km.). The height of the eye above the rail, of the average man standing on the ties, is approximately 5 feet and the horizon to him will be at a distance of 2.95 miles (4.74 km.). The sum of these two distances, 7.13 miles (11.47 km.), is the distance at which the beam from a headlight 10 feet above the rail can be seen by the average man, where the surface has a spherical shape.

The earth's surface does not always follow this true curvature so that it is quite possible, where it is flat or where dips in the track exist, so seee for distances of 20 or 30 miles (32.18 or 48.28 km.). The minimum limit of the apparent beam candle-power should be fixed at a value which would permit seeing the headlight at this distance. Fig. 2 shows that a beam of 500 apparent candle-power can be seen at a distance of about 25 miles (40.23 km.) in rainy weather and at about 35 miles (56.32 km.) in clear weather. As express trains seldom exceed a speed of 60 miles (96.56 km.) per hour, or a mile (1.60 km.) per minute, the time allowance of 20 minutes or more, between the first warning and the arrival of the train, should be ample for the protection of both the public and employees.

Intrinsic Brilliancy of Projected Beam.—It has been stated that the intrinsic brilliancy of sources of light exposed to view, should not greatly exceed 0.10 to 0.20 candle-power per square inch (6.45 sq. cm.).[6] This value is fixed however, from the standpoint of safety and good practise in the design of the usual classes of interior lighting. A review of the technical data available does not fix any values for the maximum to which the eye can be subjected momentarily without producing a state of temporary blindness Personal observation fixes this value at about 30 or 40 candle-power per square inch for locomotive headlights. To be on the safe side this value should undoubtedly be decreased by at least 50 per cent. Fig. 4 shows the intrinsic brilliancy for beams of various apparent candle-powers from reflectors of the diameters in common use to-day. It will be noted that a 16-inch reflector, giving a beam of 3,000 apparent candle-power, has a value of about 15 candle-power per square

inch (6.45 sq. cm.) of projected area, a value well within the limits of safety.

SECOND FUNCTION.

The engineman maintains his schedule by gauging the speed of his train largely with the vibration of the parts of his locomotive, but it is very desirable that he recognize while passing, such wayside objects and land marks as whistle posts, buildings, grade crossings, bridges, etc. It is only necessary for him to see these objects as he passes them, or at a range of 50 or 60 feet (15.24 or 18.29 m.) ahead of the locomotive. Such objects are

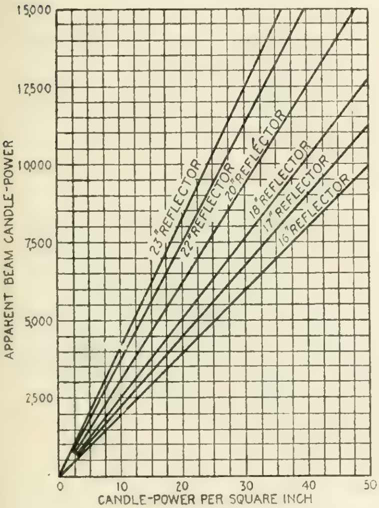

Fig. 4.

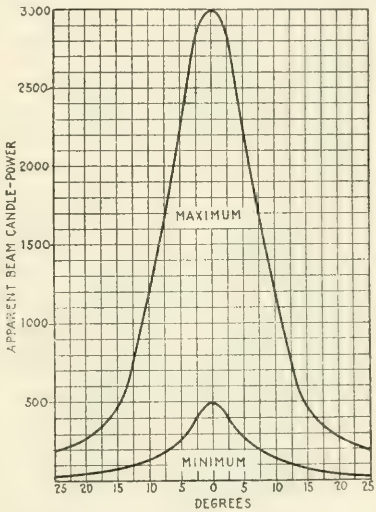

Fig. 5.

seldom farther than 20 feet (6.09 m.) from the center of the track. A line drawn through the focal center of the headlight and passing through the point 50 feet (15.24 m.) ahead of the locomotive, 20 feet from the center of the track and 3 feet (0.91 m.) above the rail, makes an angle of approximately 22½° with the axis of the beam. By referring to Fig. 5, showing the maximum and minimum values of apparent beam candle-power recommended by the Master Mechanics Headlight Committee, it will be noted that the minimum value for an angle of 22½° is 30. Reducing to foot-candles, this value becomes approxi-

mately 0.10 foot-candle or about 7 times the intensity of moonlight,[7] which should be sufficient to enable the engineman to perform this duty.

THIRD FUNCTION.

The rules for the operation of train service require that both the front and rear ends of a train shall be protected and identified by light signals at night, some of which may be colored either red, green or white. Depending upon the direction of movement, class of train, etc., there may be as many as 5 lights on the front end of a locomotive, one of which is invariably the headlight. The headlight is used only on the front ends of trains in main line service. The diameter of the reflector, intensity of beam and mounting height above the rail, are all characteristic of the headlight and are not duplicated in any other light used in the operation of train service.

FOURTH FUNCTION.

In the operation of train service, the number of the locomotive is used by the train dispatcher and tower men to identify the train. The number must therefore be illuminated at night. The headlight has long served as this source of light, the numbers, ordinarily set in the sides of the headlight casing, being illuminated through slots cut in the reflector.

FIFTH FUNCTION.

Much has been said in an effort to make this fifth function, that of enabling the engineman to see an object in time to stop his train and avoid an accident, appear to be the only important function of the headlight. A brief study of the practical conditions of train operation will show this statement to be both untrue and opposed to the safe operation of trains.

The average man dresses in what may be termed dark clothes.[8] The Columbus tests show conclusively that there is no headlight offered for sale to-day as a commercial product, that will enable the engineman to see a man in dark clothes at a safe stopping distance. These tests also show that even moderately high apparent beam candle-powers will blot out colored signals entirely or will so distort their color as to give a false indication, both of

which conditions are extremely dangerous to the safe operation of train.

Range of Visibility of Objects on the Track.—In the Columbus tests an effort was made to determine the distances at which objects on the track could be seen by the use of headlights of various apparent beam candle-powers. Where comparisons can be made, the Columbus tests in this as well as in other respects are confirmed by the tests at Avon, Ind.[9], at Madison, Wis.[10], and at Tinley Park, Ill.[11], and by individual tests by the following railroads[3]; N. Y. C. & H. R. R., C. G. W. R. R., M. C. R. R., C. &

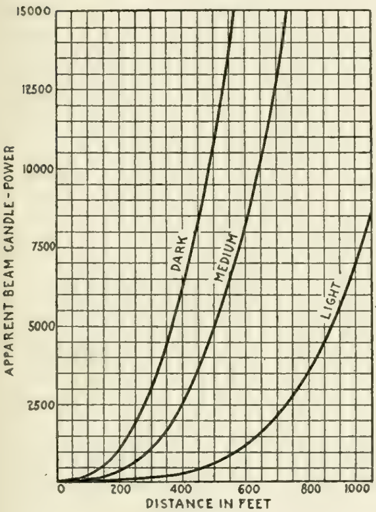

Fig. 6.

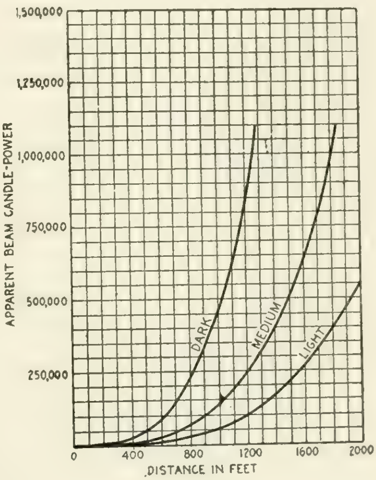

Fig. 7.

N. W. Ry., and B. & O. R. R. Fig. 6 shows the results of the tests with incandescent lamp, gas and oil-lighted headlights. The objects used were dummies, slightly larger than the average man in size and shape, dressed in overalls; the "light," in the white ordinarily worn by butchers, bakers, etc., the "dark" in the blue worn by train men, shop hands, etc., and the "medium" in an alternate blue and white ¼ in. wide, vertical stripe. The curves shown in Fig. 6 have been plotted from the three following formulas developed from the data collected in the tests:

$$\text{Apparent beam cp.} = \frac{1.061}{10^3}(\text{distance in feet})^{2.60} \text{ (for dark dummy).}$$

$$\text{Apparent beam cp.} = \frac{3.81}{10^5}(\text{distance in feet})^{3.0} \text{ (for medium dummy).}$$

$$\text{Apparent beam cp.} = \frac{8.54}{10^9}(\text{distance in feet})^{4.0} \text{ (for light dummy).}$$

These curves differ slightly from those published in the Master Mechanics report as the formulas had not been developed at the time the report was written.

The results obtained by the use of arc lighted headlights differed radically from those obtained by the use of other types of light sources, in that the distances at which the dummies could be seen were much shorter. It was not possible, on account of lack of time, to investigate the reasons for this difference. It is probably safe to assume however, that it was due largely to the color value of the light source, all of the arc lamps being rich in the shorter wave length. Fig. 7 shows curves for the arc headlights plotted from the formulas:

$$\text{Apparent beam cp.} = \frac{2.25}{10^5}(\text{distance in feet})^{3.44} \text{ (for dark dummy).}$$

$$\text{Apparent beam cp.} = \frac{5.79}{10^6}(\text{distance in feet})^{3.45} \text{ (for medium dummy.)}$$

$$\text{Apparent beam cp.} = \frac{6.04}{10^6}(\text{distance in feet})^{3.32} \text{ (for light dummy).}$$

These arc light curves are presented only as an indication of what may reasonably be expected. The arc lamps used in the tests, presumably of the best construction obtainable, were very erratic in regulation even when operated from storage batteries of 300 ampere-hour capacity. The apparent beam candle-power varied as much as 30 to 50 per cent. above and below the average selected as the rating of the lamp, whereas the variation with all the other sources of light did not exceed 6 or 8 per cent. above and below.

Safe Stopping Distance.—Fig. 8 shows two typical deceleration curves for emergency stops from a speed of approximately 60 miles (96.56 km.) per hour for a train of 12 standard class P-70 all-steel passenger coaches and a class K-2-sa locomotive.[12] This is the equivalent of the present day through express or

limited train. Curve No. 1 is for the most modern type of single shoe air brake rigging and equipment at present in regular service, while curve No. 2 is for a 2 shoe electro-pneumatic system now in process of development. It is expected that this latter system will be in rather general use within the course of the next few years. It will be noted that the present day emergency stopping distance is approximately 1,660 feet (405.97 m.) after the application of the brake, while that of the near future is about 1,235 feet (376.42 m.).

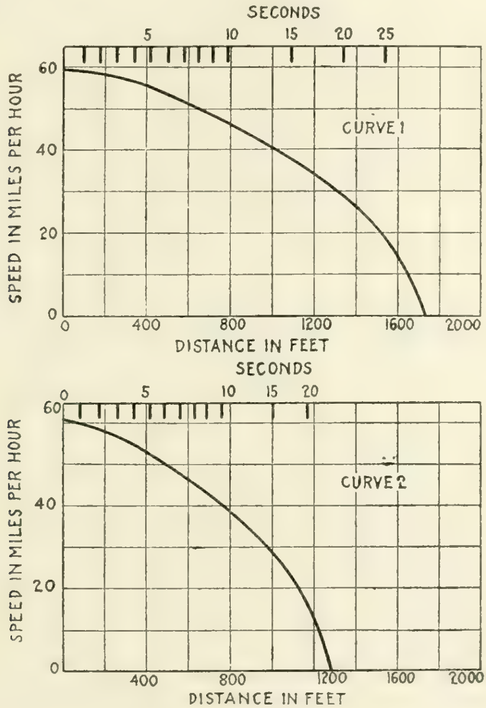

Fig. 8.

In the Columbus tests it was found that the dark dummy could be seen at a distance of about 500 feet (152.4 m.) with an apparent beam candle-power of approximately 10,000 for an incandescent lamp headlight, while it required about 60,000 from an arc headlight. This distance was increased to 1,237 feet for an arc light of 1,000,000 apparent beam candle-power. Incidentally this

is the extreme distance at which there is a contrast between the object and the back ground and is not the distance at which the object assumes shape and form. It is therefore evident that none of the headlights tested at Columbus (the variety covered all commercial sizes and types, over 200) had sufficient apparent beam candle-power to enable the engineman to see an average man on the track in time to stop his train and avoid an accident, and that it is doubtful whether the engineman could see him at even the prospective future emergency stopping distance.

It must not be forgotten that the engineman does not apply his emergency at the exact instant he thinks he sees and object on the track. He first waits until the object begins to assume form and shape, after which he endeavors to attract attention by blowing his whistle. This all requires time, probably 50 to 75 per cent. of the time required for making an emergency stop, so that the locomotive has passed the safe stopping distance for the average man by several hundred feet, at the instant the emergency is applied.

Classification Signals.—It is necessary in the operation of train service, that the engine and tower men shall be able to identify all trains passing them. A means of identification has been provided in the form of classification lamps. At the head end of the train, these are placed one on each side of the front end of the locomotive, at about the height of the horizontal axis of the smoke box. Under certain conditions additional lights are sometimes placed on the ends of the pilot beam. These lights are usually white or green, while red and combinations of one green and one red are used at the rear end of the train.

The most difficult condition under which it is necessary for the engineman to read these signals, is that of 2 trains approaching each other, head on, on adjacent tracks. Under this condition the opposing headlight tends to interfere with the proper reading of the signals. Fig. No. 9 shows the distances at which classification signals can be read correctly with opposing headlights of equal apparent beam candle-powers. This curve has been plotted from the formula;

$$\text{Apparent beam candle-power} = \frac{4.65}{10^{12}}\overline{(2{,}000 - \text{distance in ft.}}^{\,5}$$

developed from data secured in the Columbus tests. This curve also differs slightly from that shown in the Master Mechanics' report.

When two locomotives approach each other on adjacent tracks, the classification lamps on one locomotive are obscured to the engineman on the other, by the front end of his locomotive when the two locomotives are about 600 feet (182.88 m.) apart. With opposing headlights of 2,500 apparent beam candle-

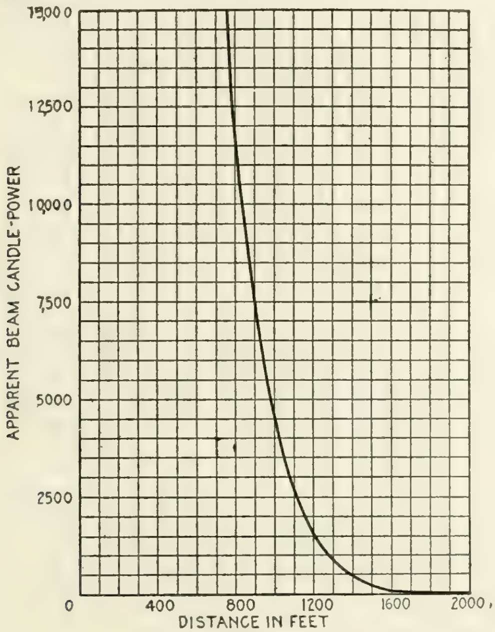

Fig. 9.

power, these lights can be correctly identified at about 1,100 feet (335.28 m.). Subtracting the 600 feet above referred to, gives 500 feet (152.4 m.) for the movement of the train before the signals disappear. For express trains running at 60 miles per hour, this distance, 500 feet, is equivalent to slightly less than 3 seconds, during which time the signal must be read.

Semaphore and Switch Signals.—The Columbus tests show some very peculiar, as well as interesting, conditions in connection with the operation of colored light signals, when headlights

of comparatively high apparent beam candle-powers are used. Light falling upon a roundel or signal lens will be reflected in some degree. Depending upon the position of the roundel or lens, the intensity of the headlight beam, etc., the light may be reflected back to the engineman or it may be refracted, under which condition the signal will assume an entirely different color. In a number of instances green or white indications were secured from red roundels, a condition that is extremely dangerous, since white means safety to the engineman, while red means danger or stop. This condition is very pronounced when

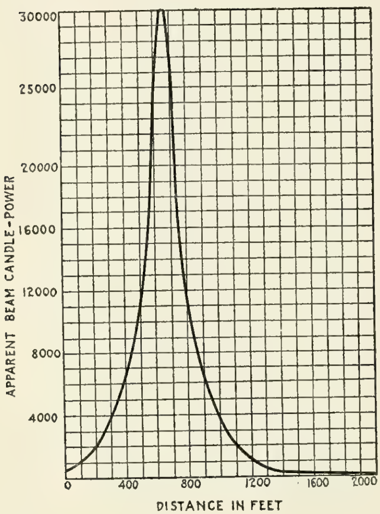

Fig. 10.

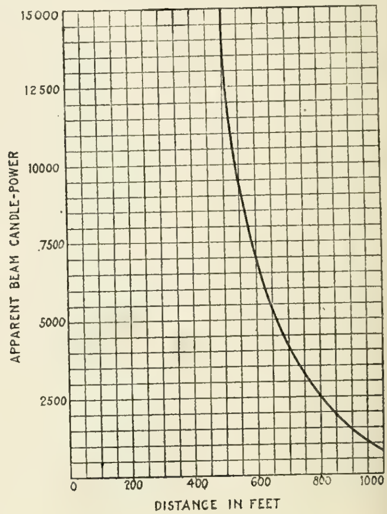

Fig. 11.

the lamp in the signal lantern is not lighted, although when the lantern is lighted, it is sufficiently pronounced to be dangerous, especially with the higher apparent beam candle-powers. Under certain conditions the signal indication may disappear entirely, and this applies to hand signals as well, or it may have the appearance of having been shifted from its former position. Dwarf switch signals are very liable to these troubles.

There also appears to be a fairly well defined region in which fixed signals of this character can be read correctly, while outside of this region it is almost certain that there will be false indications. It has not been possible so far to so analyze the test

data available as to plot curves for each kind and color of signal. All of this data has been lumped together, however, giving the curve shown on Fig. 10. A formula has not been developed for this curve because the test data are somewhat incomplete at certain distances and also because the incorrect observations must be discounted to some extent to cover possible errors in noting the observations, tabulating, etc.

Colored Hand Signals.—Fig. 11 shows the approximate distances at which fusees, red lantern flags and other hand signals may reasonably be expected to give correct indications. The data for all of the hand signals used have been lumped together and a formula for the curve has not been developed, for the reasons above given.

COMMENTS AND CONCLUSIONS.

The first or most important function of a headlight fixes the value of the apparent beam candle-power from the standpoint of its being a sign of warning of the approach of danger. The data given in the first part of this paper show that the maximum and minimum values of apparent beam candle-power (3,000 and 500 respectively) recommended by the Headlight Committee of the Master Mechanics Association are well founded.

The fifth or least important function, fixes the value from the standpoint of enabling the engineman to see objects on the track without there being any interference with the reading of colored signals The maximum and minimum values may be readily determined by plotting all of the visibility curves on one sheet and noting the points at which the various curves intersect each other. Such a plot is shown on Fig. 12, and this also confirms the Master Mechanics recommendations. It will be noted that there will be difficulty, at distances less than the maximum at which the light dummy can be seen, in correctly identifying classification lamps with more than 6,500 apparent beam candle-power, semaphore signals with over 6,000 and hand signals with 3,000.

All of the headlight tests conducted to date have developed very interesting and very valuable data. In the reports of the tests however, the data has not always been presented in such shape

that it can be compared with that of other tests. The effort has been made in this paper to present such data as is available, in terms that may be conveniently measured and compared. Some of the data herewith is not complete nor definitely established and it is to be hoped that others will endeavor, as tests are conducted in the future, to prove or disprove the correctness of the

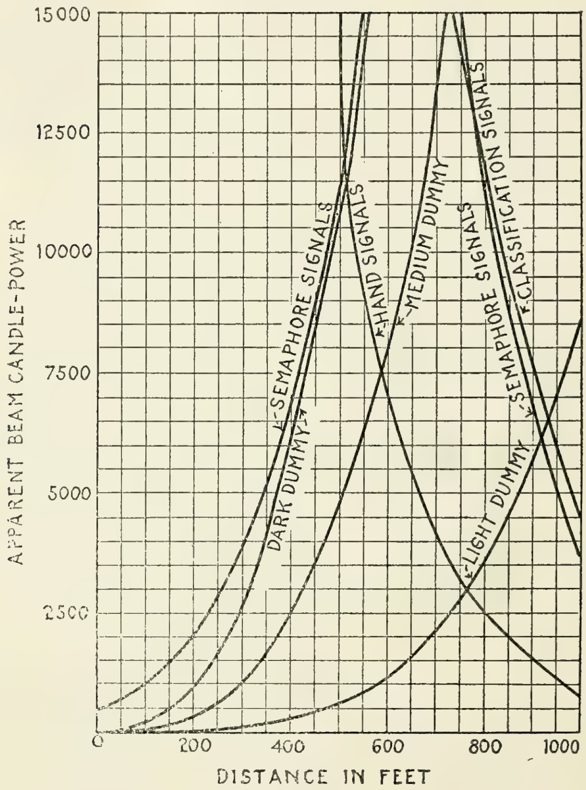

Fig. 12.

curves and formulas given, and in addition, to develop such new formulae as the results of the tests may seem to warrant.

The practise of referring to the wattage of the lamp, the diameter of the reflector, the candle-power of the lamp, the distance at which an object can be seen, etc., in attempting to establish the value of a headlight, should be discouraged as much

as possible, as its value cannot be fixed in this manner. Reference to the apparent candle-power and angular spread of the projected beam should be used instead.

Future investigations should include: the establishment of an accepted method of photometering, an analysis of the color values of the several light sources, the determination of the effect of variations in the color value of the projected beam upon the visibility of objects and signals, and the fixing of standards for the size, shape, etc., of light sources.

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DISCUSSION.

Mr. W. R. Mott: I believe that the inverse square law for practical purposes is applicable to headlights and searchlights.* It is customary to use the inverse square law as sufficiently close an approximation in practical searchlight work. While scientifically the inverse square law is only an approximation, yet by geometrical optics with the usual large light source, it can be

* See page 28, Nerz. Searchlights.

shown to be a rather close approximation. Some years ago, I made a few tests on the change in photographic power at different distances in the center of the illuminated field from a Macbeth open arc flame lamp and found the inverse square law to apply with close approximation up to 10 feet.

In regard to Fig. 12 I should like to know what effect on the distance to a dark dummy would result from the ground being covered with snow. Also, what would be the distance to see the dummy with headlight plus starlight and also with headlight plus moonlight.

Mr. L. C. Porter: Mr. Minick's paper—a summary of probably the most extensive headlight tests which have so far been conducted—contains a great deal of valuable information on which there has been little published. There are several points in the paper which might be expanded somewhat.

Mr. Minick speaks of the "angular spread of the beam." It will be interesting to know just how Mr. Minick determines the edge of the beam. With fairly concentrated light sources, headlight beams thrown along the ground have an apparent edge; that is, there is a place where the intensity falls so rapidly that it makes an apparent line on the ground. With large light sources, giving beams of considerable spread, such as oil headlights, this is not so marked. There is, however, no definite point where the light ceases, which can be called the absolute edge of the beam. For example, in Fig. 5, taking the maximum beam candle-power curve, it is apparent that a sudden change in the decrease in illumination starts to take place approximately at the 15 deg. point. I have made photometer tests of a large number of various headlights and it has been my general experience that with a headlight giving such a beam there is an apparent edge along the ground; this edge will generally be at approximately the point where the beam candle-power curve starts very decidedly to flatten out—such as the intersection of the 15 deg. and 500 candle-power lines in Fig. 5. These points I have found to be generally in the neighborhood of 10 per cent. of the candle-power at the center of the beam, and this figure has been found very convenient as an arbitrary value for the edge of the beam.

On the eighth page Mr. Minick mentions the number of the locomotive being read by train dispatchers, tower men, etc. Considerable experimental work has been done in Schenectady, in determining the best location for locomotive numbers on a headlight. Headlights have been tested with number plates across the front, on each side, and also at an angle. It has been found that very satisfactory results can be obtained with the number plates located approximately 30 deg. to the face of the headlight, extending back from the front of the headlight. This enables satisfactory reading of the numbers both from in front of an approaching locomotive and also from the sides as the locomotive passes; in fact, this arrangement allows a longer period for determining a locomotive number, when a locomotive is approaching and passing a tower man, than any other arrangement tried.

On the eighth page Mr. Minick states that there is no commercial headlight offered for sale to-day which will enable an engineman to see a man in dark clothes at a safe stopping distance. This belief, together with the glare effects of a powerful headlight, seems to convince Mr. Minick that there is no demand for a high-powered headlight. It seems to me that there are two conditions to be met: one, the single track, western road, and the other the double track, eastern road, equipped with fairly closely located signals and running through suburban towns. For the former, I should think that a powerful headlight would be an advantage. While it might not enable an engineer to bring his train to a standstill if an obstruction were seen on the track, it should at least enable him to reduce speed so that the severity of the collision would be minimized.

In the range of visibility curves shown in Fig. 7 it is seen that in order to see a dark object at 1,200 feet a beam candle-power of 800,000 with an arc is necessary. There is now on the market a standard incandescent headlight consisting of a silver-plated parabolic reflector 19 5/16 in. (56.19 cm.) in diameter, of 2¾ in. (6.98 cm.) focus, equipped with a 6-volt, 18-ampere tungsten lamp, which has an apparent beam candle-power of approximately 900,000, which, from the curve shown on Fig. 7, should be ample for seeing a dark object at 1,200 feet, or a medium object at 1,600 feet; and if the light source were an

incandescent lamp this distance would be increased considerably.

There have been some experiments carried on to determine the relative efficiencies of pressed glass parabolic reflectors and spun metal silver-plated parabolic reflectors. With the former it is not mechanically practical to make a reflector of short focal length; therefore, assuming the same diameter, the metal reflector will utilize a higher percentage of the total light flux. On the other hand after the headlights have been in service for some time the coefficient of reflection of the glass is generally higher than that of the metal and its accuracy is also greater. Tests of new independent reflectors have shown small difference between an 18-inch (45.7 cm.) silver-plated metal reflector of 1¾ in. (4.44 cm.) focus and an 18-inch pressed glass parabolic reflector of 5½ in. (13.9 cm.) focus—that is, as far as the resultant beam goes, the glass reflector having a slightly higher intensity and slightly narrower beam. In regular service, however, I believe the glass reflector would have considerable advantage because the metal reflector, if frequently polished under roundhouse conditions, is much more likely to become scratched and lose its reflecting surface than is the glass. The labor expense in keeping the reflectors polished should also be lower for the glass, as it is a very simple matter to clean off the glass surface, whereas the metal surface requires considerable hard work to polish.

On the sixteenth page attention is called to the difficulty of giving thorough and complete headlight specifications. It seems to me that a good specification would be the average beam candle-power measured at a distance of several hundred feet over a certain definite angular spread.

Mr. Minick in referring to the lamp, speaks of giving the wattage, candle-power, etc. I believe that it would be of value if the dimensions of the light source itself were given, as this has an enormous effect on the resultant beam. The more nearly the light source approaches a theoretical point located at the focus of a lens or reflector, the less the spread (and consequently the greater the maximum intensity) of the beam. As an example of the enormous effect, which this has on the resultant beam, it is interesting to note that tests of a 6 volt 143 cp. lamp having a

light source which could be contained in a cylinder 2½ mm. in diameter by 5 mm. long in a 19 5/16 in. (49 cm.) silver-plated parabolic reflector of 2¾ in. (6.9 cm.) focus, gave a maximum beam candle-power of 950,000; while a 1,500-cp. 35-volt lamp having a light source 8 mm. by 8 mm., in a similar reflector, gave 1,100,000 beam candle-power.

The former equipment had a multiplying factor (ratio of candle-power of light source to beam candle-power) of 5,340; while the latter had a multiplying factor of but 733.

In the practical operation of headlights, the factor of locating and maintaining the light source exactly at the focal point of the lens or reflector probably has more to do with satisfactory operation than any other factor.

The tests which I have made on a headlight consisting of a 16 in. (40.6 cm.) parabolic reflector of 3 in. (7.62 cm.) focus, equipped with a 36-watt, 6-volt tungsten headlight lamp (this lamp having a filament which can be contained in a cylinder 1½ mm. in diameter by 3 mm. long) show that a very slight change in the location of the light source makes an enormous change in the resultant beam. For example: Moving the light source ¼ in. (0.6 cm.) back of the focus decreases the maximum intensity at the center of the beam 100 ft. (30.48 m.) away, from 21.5 foot-candles to 0.87. Moving it ¼ in. to the side distorts the beam, throwing the center of the beam approximately 4 ft. (1.2 m.) to one side, at a distance of 100 ft.; and reduces the maximum intensity from 21.5 to 12.7 foot-candles.

The accompanying curves, Figs. A and B, show the distribution with the lamp in focus, ¼ in. (6.3 mm.) ahead of the focus, ¼ in. behind the focus and ¼ in. side of the focus. Curves in Fig. A show the change in intensity as the light source is moved either back of or ahead of the focus in 1/16 in. (1.58 mm.) steps.

The fact that once the filament of an incandescent lamp is located at the focus of the lens or reflector it will remain there until the lamp fails, should be a factor of enormous advantage to the incandescent headlight.

The accompanying curves also indicate the absolute necessity of having some focusing device on the headlight, as it is not practical to keep an absolutely constant light center length on

concentrated filament lamps of the same type. Therefore, when a new lamp is installed it should always be refocused.

On the tenth page in the formulas given for the incandescent

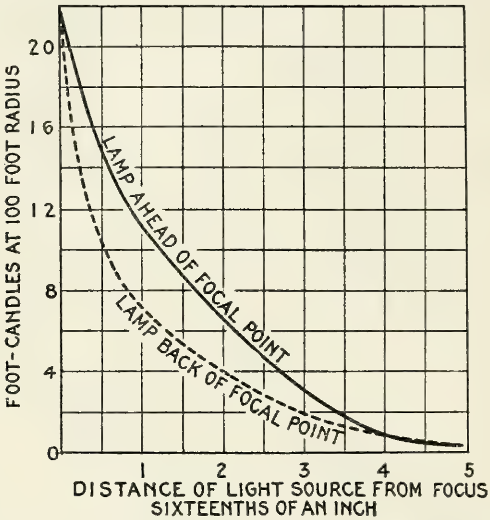

Fig. A.—Curves showing change in maximum intensity of beam (at center) of an incandescent headlight (16-inch silver-plated parabolic reflector of 3-inch focus) equipped with a 6-volt, 36-watt tungsten headlight lamp.

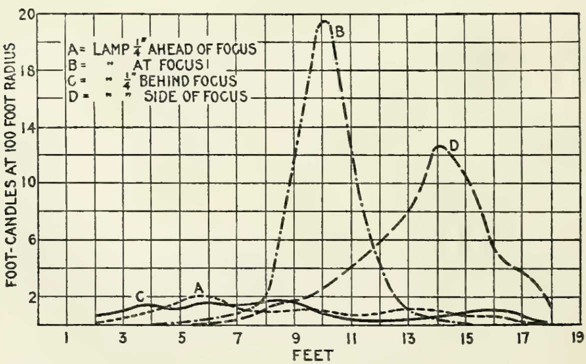

Fig. B.—Distribution curves across beam from headlight having a 6-volt, 36-watt, vertical helix tungsten headlight lamp equipped as described in Fig. A.

lamp,—raising the distance in feet by an increasing candle-power would indicate that as the distance increases the differences in "pick-up" distances for a man dressed in dark, medium or light

clothes decreases. There may be some physical condition which causes this, but at first thought it seems illogical that at distances of several thousand feet a man in dark clothes would be just as discernible as a man in white; while at a shorter range a man in white would be discernible with a very much lower intensity of light.

On the same page, Mr. Minick suggests that it is the color of the light which enables an incandescent headlight to "pick up" a man further than an arc of equal beam candle-power. It has been my experience that the steadiness of the incandescent lamp also has considerable to do with this.

It is interesting to note on the next page that to-day the emergency stopping distance of an express is practically 1,660 ft. (506 m.). From the incandescent formulas given on the tenth page, we see that the beam candle-power of approximately 235,000 will pick up a man in dark clothes at 1,660 ft. Incandescent headlights have already been produced, giving beam candle-powers of over 1,000,000. With such a headlight surely an obstruction on the track could be picked up in sufficient time to reduce the speed to such a point that the severity of a collision would be greatly lessened. A headlight of this power would, of course, be altogether out of the question on the double-track eastern roads; but it should have some application on the single-track western roads.

The fact that practically any power headlight can be obtained by simply changing the incandescent lamp used, and that this can be easily dimmed, makes the incandescent headlight a most elastic, reliable and efficient equipment for locomotives.

Mr. G. H. Stickney: One point of great value in this paper is that it represents the views of a light user who has had an opportunity of making a careful, discriminating study of his lighting problem, and who has no implied prejudices in favor of any particular make or type of apparatus. It seems to me that such papers are especially desirable contributions to our Transactions.

The author refers to the range of headlights being affected by the curvature of the earth, track curves, etc. In some cases it has been found practicable to extend the range of headlights by

reflecting a portion of the beam upward, so that the beam can be seen against the sky at a considerable distance.

The most serious objection to powerful headlights is the intrinsic brilliancy which produces serious glare when looking into the headlight. My first thought when encountering this condition was that it might be partially overcome by the use of two or more headlights instead of one, thereby increasing the illumination effect for a given degree of intrinsic brilliancy. I understand from Mr. Minick, however, that the method of using classification numbers now in vogue on American railways makes this expedient impracticable.

Mr. Porter referred to the question of the advantage of the glass reflector over the metallic. I think one other point is the greater accuracy of the glass reflector, through which less light is lost by being reflected outside the beam.

One serious trouble which the railroads have had to meet is introduced by the headlight specifications prepared under the authority of the various legislative bodies. Unfortunately some of these specifications have been drawn up by those unfamiliar with the laws of light and the conditions under which headlights are used. Some of these specifications tend to introduce unsafe conditions, some of which have been mentioned by the author. In some instances they require considerable expenditure on the part of the railway, where a better effect could be obtained at a smaller cost. For example: The requirement that a headlight shall be provided with a source giving 1,500 unreflected candle-power, simply demands a powerful light source, but does not provide for a proper utilization of the light. The tests conducted under the auspices of the State of Nevada, at Reno, showed that a 140 cp. incandescent lamp, with a suitable reflector, was able to illuminate a track so that objects could be seen at a greater distance than with an arc headlight commonly used to meet the 1,500-cp. specification. In this case the test prevented the adoption of the wasteful arbitrary standard, but in some other states the railroads have not been so fortunate.

Just a word about the inverse square law as applied to the headlight beam: It is difficult to get accurate tests to confirm the application of the inverse square law, as the intensity of light

varies considerably through very narrow angles; but practically all tests which we have made, or seen, seem to confirm the application of the law except at short distances, where the beam is not homogeneous. Such tests have shown that the law applies approximately from the actual light source as an origin, and not from a virtual source at some distance behind the reflector, as some have assumed. I have worked out a theoretical explanation based on the fact that the original light source within the reflector is larger than a dimensionless point. This seems to confirm results obtained by actual measurements.

Mr. W. H. Rolinson: I wish to ask Mr. Minick if any action has been taken by the railroad companies or organizations of railroad people in an endeavor to have Congress pass a federal law regulating the size and character of locomotive headlights with the object of having a uniform law instead of many laws by many states, many of which vary greatly from each other.

Mr. A. R. Ayers (Communicated): Mr. Minick mentions on the fourth page of his paper three conditions of a negative character which have apparently been entirely overlooked by the framers of many of the present state laws, especially in so far as they concern two, three and four-track railroads. On such railroads, trains usually run frequently and are operated almost entirely by signals; so that it is absolutely necessary for safety that the brilliancy of the headlight shall not interfere with the correct reading of colored signals. Repeated tests have shown that the so-called high power headlights do interfere with the reading of colored signals, either fixed or on trains ahead; and it is a grave responsibility to insist on the use of such headlights under such conditions.

Mr. T. R. Cook (Communicated): The subject of this paper, the locomotive headlight, is of great interest to the railroad and technical men of the country, as it is a subject that has heretofore received very little scientific investigation and is brought strongly before parties concerned by the prominence given it by state legislation.

An engineman when running a locomotive is not required to pick out smooth parts of the road as is a man operating an automobile. The route is set up for him and whether it is clear or not

is indicated by signals. Without question, headlights should be of sufficient intensity to allow the engineman to see objects in the immediate foreground for his guidance in entering passenger terminals, shifting in terminal yards and to locate himself by landmarks when on the road. It is, however, against common sense to provide the locomotive with a headlight of such intensity that it tends to destroy the accuracy of reading signals of a block system which has been installed at great expense to provide safety for transportation; or to provide a locomotive with a headlight of such intensity that its rays will obscure the vision of an engineman of the rear end of a preceding train, or a red lantern or fusee on the track which has been placed to protect the preceding train. This latter condition requires extreme care in the design of the headlight. The tests for the American Railway Master Mechanics' Association at Columbus demonstrated, without question, that an opposing headlight, having an apparent beam candle-power of over 3,000 tends to destroy the accuracy and liability of picking up danger signals as mentioned above, and the accuracy of picking up these danger signals decreases rapidly with the increase of the apparent candle-power of the opposing headlight. I am thoroughly convinced that the American Railway Master Mechanics' Association recommendations that a headlight should not have an apparent beam candle-power over 3,000, or less than an apparent beam candle-power of 500 was well taken. The maximum limit of 3,000 apparent beam candle-power is the greatest candle-power that can be used without jeopardizing the interpretation of signals upon which safety of transportation depends, while the minimum requirements of 500 candle-power is sufficient for an engineer to pick up landmarks along the right-of-way and operate with safety in passenger terminals and in making switching movements.

Mr. J. L. Minick (In reply): Before answering the questions raised it might be well to explain further regarding the use of the term "apparent beam candle-power." The intensity is so extremely high that it cannot be measured directly by the means ordinarily employed in rating incandescent lamps. The most convenient method appears to be that of taking foot-candle readings and from these to calculate the candle-power values. The

calculations are based upon the assumption that the law of inverse squares holds true for the beam of light projected by a parabolic reflector or semaphore type of lens. While we do not know definitely that this law holds true, Fig. 1 shows that it holds within safe limits and the term "apparent beam candle-power" is used to indicate that the candle-power values are calculated on this assumption.

In reply to Mr. Porters' question concerning angular spread of beam, if the candle-power values are plotted on polar co-ordinate paper instead of as shown in Fig. 5, a fair approximation of the angular spread may be had.

It is difficult to read locomotive numbers when they are placed across the front end of a locomotive, especially on a multiple track road, like the Pennsylvania, where there may be as many as six tracks opposite the tower. The number must be placed high enough to be visible to the tower man when other trains are passing between it and the tower. The number must therefore be placed on the side of the locomotive. The most convenient location seems to be on the headlight as this is easy of access for cleaning and the headlight serves as the source of light.

It may be safe to use high candle-power headlights on single track roads not protected by colored signals. On multiple track roads and where colored signals are used this type of headlight becomes an element of serious danger. Even comparatively low candle-powers interfere with the correct reading of signals. While there is the possibility of a more or less constant error in the reading of colored signals by enginemen, every effort is being made to eliminate all errors. The engineman and fireman are each required to call all signals, surprise tests are conducted regularly and the failure to promptly and accurately obey signals is usually followed by severe discipline. Even under these conditions wrecks occur. It would therefore seem very unwise to require the use of headlights of high intensities. A single mistake in reading signals may be fatal.

Mr. Porter is in error in his reference to Fig. 7. This figure refers only to arc lamps. If the curves shown in Fig. 6 are extended or if they are replotted from the formulas given for incandescent lamps, the proper values will be secured.

Mr. Stickney has proposed the use of two headlights. Rules for the operation of train service were formulated and adopted by the railroads some years ago. They specify definitely the numbers, color and location of all lamps used on a train. They have been in general use for many years and they have so frequently been recognized by the courts that they are now the accepted standard. It would be extremely difficult to change them sufficiently to permit the use of two headlights. I understand that two headlights are used on English locomotives with success.

In reply to Mr. Rolinson's question—a federal law would be of advantage only in that it would probably tend towards unifying the state laws. There are, I believe, several bills before Congress at this time, one of which requires a comprehensive investigation. I believe the railroads will be willing to equip their locomotives with any type of headlight required by law, provided they are not compelled to provide one type in one state and an entirely different type in another state.

All readings were taken at the uniform distance of 25 feet (7.62 m.) in the laboratory. The photometer used was rather large and cumbersome and it is possible there was some error in taking some of the readings. The errors, however, were corrected as far as possible. Attempts were made to check the laboratory tests by tests in the open atmosphere at long distances. These check tests were not successful and a second check test was made in a large foundry. This test was successful indicating that there must have been some atmospheric condition to interfere with the check tests. Additional tests were conducted at Altoona in which it was attempted to secure readings of only the center of the beam at distances of 25, 50, 100 feet, etc., from the focal center of the headlight. These tests indicate that readings can be taken at almost any convenient distance, although at 25 feet there is possibly a greater chance of error than at greater distances. Owing to the crowded condition of most railroad shops it will be difficult for railroads to make tests of this kind where the reading distance is greater than 50 or 60 feet (15.24 to 18.28 m.).

THE DEVELOPMENT OF DAYLIGHT GLASS.*

BY EDW. J. BRADY.

Synopsis: This paper gives a short description of an investigation which was conducted for the purpose of producing a glass that would give the effect of average daylight when used with a gas or a tungsten lamp. The difficulties encountered in making such a glass are set forth. Curves showing the per cent. transmission of a number of the glasses made are given. Two instruments (one for producing any required spectral energy distribution, and the other for determining the departure of a given glass from a standard) developed during the investigation are described and illustrated.

The arts and sciences have long felt the need of an artificial light having the same spectral composition as that of daylight. This need has been partially filled by various lamps and devices. Among these may be mentioned the carbon dioxid tube, the carbon arc, the tungsten lamp and the Welsbach mantle. The carbon dioxid tube has an emission the integral color of which approximates white light. All the others must have their color altered either by means of absorbing media, such as dyed gelatine on glass, or strips of various colored glass placed side by side. All of these have their shortcomings, either due to a lack of adaptability or to their inability to perform the function as completely as is desired.

Until investigators bring forth a practicable light source having an energy distribution comparable with sunlight, we will be compelled to resort to the so-called "subtractive" method for producing sunlight or white light.

There is but one way to properly perform this subtraction of the excess energy, and that is by means of a single glass. A glass which will withstand the temperature to which it is subjected without fracture or change of color and one that can be easily blown or pressed into the various forms demanded by the modern lighting engineer. It was to the problem of the production of such a glass that the author addressed himself.

Daylight involves two factors—intensity and color. With the former we are not concerned at this time. As for the latter,

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

especially to the person trying to make exact measurements, there is no statement more indefinite than a simple unqualified reference to the color of daylight.

The color of daylight may be anything from the intense blue of a cloudless sky to the deep red hue of the setting sun. All of these are daylight and furthermore all may be modified by the surroundings, such as the reflection from green foliage or from painted buildings. For our purpose the color of average daylight is the color of a black body at a temperature of 5,000 deg. abs. This has been found by various spectrophotometric measure-

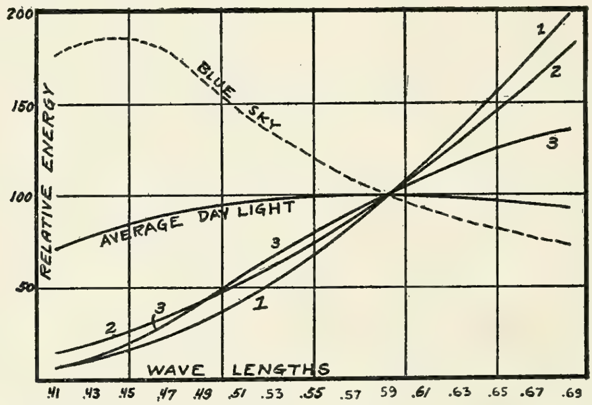

Fig. 1.—Curve showing energy distribution of natural and artificial light sources. 1. 1.24 w. p. c. tungsten. 2. 0.65 w. p. c. tungsten. 3. Welsbach mantle 0.75 per cent. ceria, 99.25 per cent. thoria.

ments[1] to be equivalent in color to a white surface illuminated by a clear sunlight at midday.

In Fig. 1 is shown the energy distribution of various light sources: They are all made equal at 0.59μ, so that the total luminosity in each case is approximately equal. Curves 1, 2 and 3 are of artificial sources and on the same sheet are shown the curves of both average daylight and the blue sky, to which the distribution of the above mentioned artificial sources might be made to correspond by means of a suitable glass. It will be noted that the ordinary Welsbach mantle, due to its emission in the neighborhood of 0.53μ and 0.55μ and its deficiency in the

[1] Ives, Herbert E., Color Measurements of Illuminants—A Resume; TRANS. I. E. S., vol. V, 1910, p. 189.

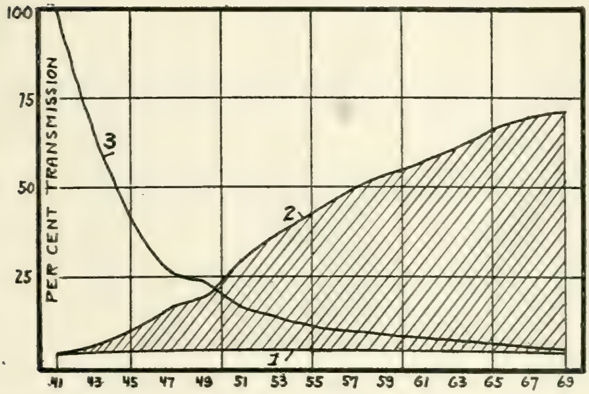

Fig. 2.—Shaded area is proportional to the amount of energy that must be absorbed by an ideal daylight glass. 1. Energy distribution of average daylight. 2. Energy distribution, Welsbach mantle, 0.75 per cent. ceria. 3. Transmission of an ideal daylight glass for use with mantle.

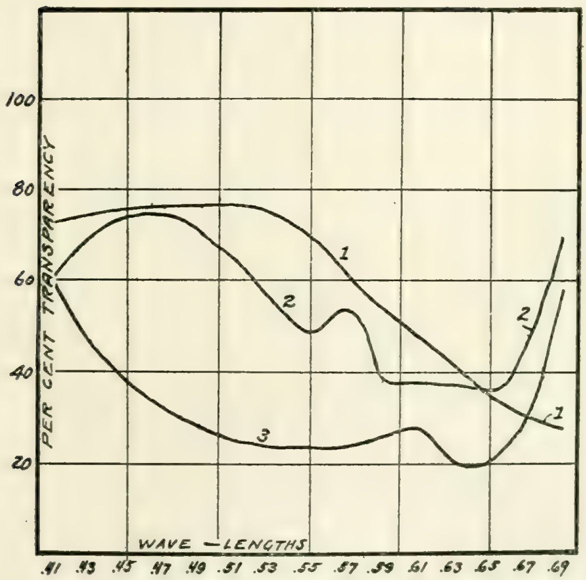

Fig. 3.—Per cent. transparency of potash lead glass colored with: 1. Black oxid of copper—green. 2. Cobalt oxid copper—blue. 3. Black oxid nickel—purple.

deep red, is particularly well suited for use with the daylight glass.

In Fig. 2 is shown the distribution of energy in the average daylight and the ordinary Welsbach mantle. The shaded area compared with the area below curve No. 1 is a measure of the amount of energy that must be absorbed by a glass to convert the light of the mantle to that of average daylight. On this same sheet is shown curve 3, the transmission of a hypothetical blue glass which would perform the above function. This assumes zero absorption at 0.41μ, which is of course impossible. It gives, however, the general character of the required absorption. It is to be borne in mind at the beginning that any blue glass will not do. It must have a particular and definite absorption and this can be obtained only by combining various colors in the proper proportion.

Figs. 3 to 7 inclusive are curves showing the percentage transmission of glass containing some of the various coloring materials that we have at our disposal and by which we must try to duplicate the absorption given above. The foregoing, then, is a brief statement of the problem, together with a glance at the few available absorbing materials that we have at our command.[2] In this paper the author has confined himself to the subject of glass and has not touched upon the general question of daylight.

Practically all the glasses in use are thought to be either metallic silicates or mixtures of metallic silicates. The proportions of the various silicates or the acids and bases which go to form the silicates, may vary between rather wide limits, but when they are added in certain proportions, determined by long experience, and having regard to the use to which the resulting glass will be put, the result is a very stable compound, resisting for a long period the action of all chemicals and acids, except hydrofluoric. If free from impurities it is a transparent non-crystalline substance, practically free from color, *viz.*, it absorbs all the wavelengths within the visible spectrum in the same proportion. If certain impurities are present the glass absorbs different wave-lengths

[2] A full treatment of the theory of the production of artificial daylight is contained in the article, "Artificial Daylight," by Herbert E. Ives, *Journal of the Franklin Institute*. May, 1914. The daylight glass here described was first exhibited publicly on the occasion of the presentation of that paper on February 18, 1914, a large table being illuminated by gas daylight units.

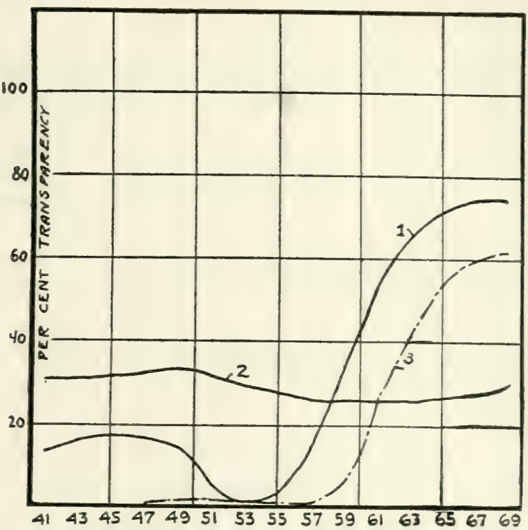

Fig. 4.—Curves showing transparency of some "colloidal" glasses. 1. Gold ruby glass—red. 2. Gold ruby imperfectly reheated—faint blue. 3. Copper ruby—"flashed" red.

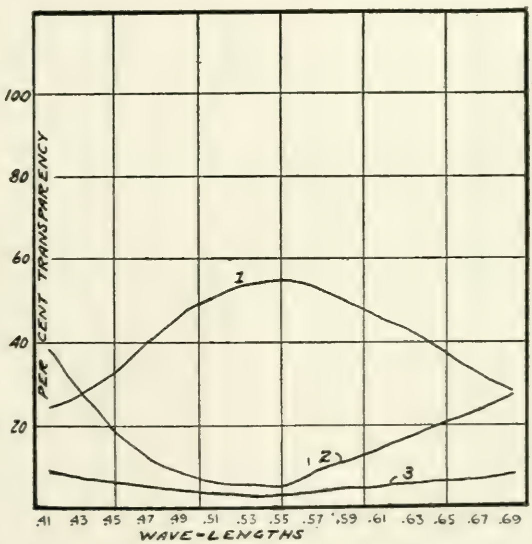

Fig. 5.—Curve showing per cent. transparency of potash lead glass colored with: 1. Iron oxid (ferrous)—bottle green. 2. Manganese dioxid—reddish purple. 3. Manganese plus iron—almost colorless.

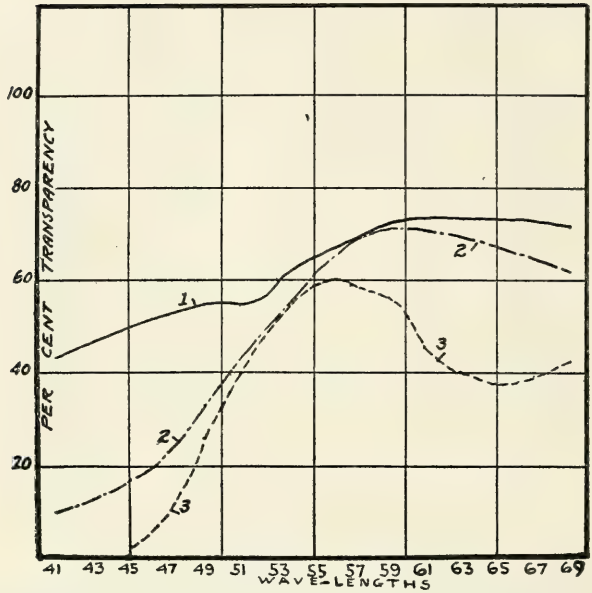

Fig. 6.—1. Sodium selenate in soda lime glass—flesh tint. 2. Tungsten oxid in potash lime plus reducing agent—yellow. 3. Chromic oxid—green.

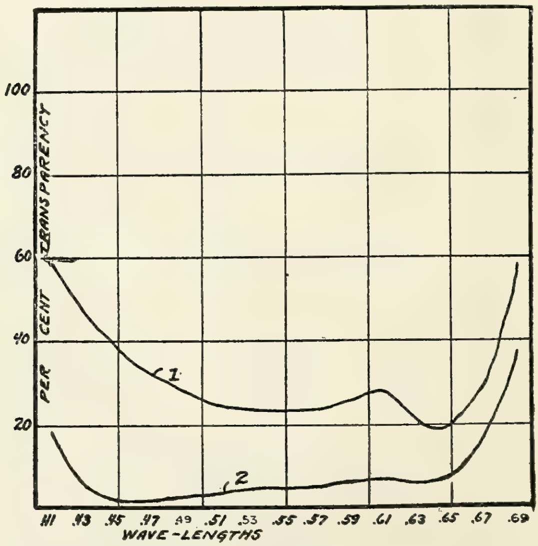

Fig. 7.—Transparency of black nickel oxid in: 1. Potash lead glass—purple. 2. Soda lime glass—brownish purple.

in unequal amounts and the result is a glass tinged with color. Under factory conditions it is practically impossible to obtain both sand and pots that are absolutely free from iron, and it is the presence of this element which produces the green tinge so often noticeable in the cheaper grades of glass. Glass makers offset this by introducing a so-called decolorizer, a material which produces a complementary color or destroys the color by chemical action. Manganese is generally used for this.

The transparency of both iron oxide and maganese are shown in Fig. 5, and their product is represented by the almost straight line which on the same scale would represent the transparency of the decolorized glass. These pieces were selected at random; otherwise the line three could have been made quite straight.

Most of the coloring materials are in the glass in solution. When in this condition the glass is easily worked and will withstand variation of temperature and reheating without loss or change in color. Some of them, however, will not withstand prolonged heating, as the color will gradually "burn out" or become less dense. There are others which produce a coloring effect only when they are present in the form of colloidal suspension. Among the latter may be mentioned copper and gold.

Colloidal colors are very difficult to work and no success was met with in the attempts to incorporate gold in a daylight glass. Gold ruby comes out of the pot clear, and the color must be developed by reheating. If the reheating is carried too far it assumes a brownish tinge by reflected light and a faint blue by transmitted light. Gold ruby in combination with certain other coloring matters would produce an excellent daylight glass, but the impracticability of working this alone not to speak of combining it with other colors, makes its successful use highly improbable.

The transparency of these glasses is shown in Fig. 4. Curve 1 is that of gold ruby and curve 2 is a similar glass if the reheating is carried too far, as mentioned above.

Colloidal copper, the transparency of which is shown by curve 3, colors glass so densely that it is generally "flashed" on the surface of a crystal glass, the actual thickness of the colored glass being a small fraction of a millimeter.

Copper ruby is more difficult to work than gold ruby, and if it is not manipulated in the proper way the glass will become opaque and resemble sealing wax.

A daylight glass, aside from the character of the light it furnishes, must be a practicable glass. The requirement as to thickness and concentration using the more dependable coloring matters are sufficiently severe without introducing any special heat treatment. One might be made having manganese as one of the constituents. This element has about half a dozen different oxids. The depth of the resulting color would be extremely uncertain and would depend entirely upon the heat treatment of the glass. Aside from the insurmountable difficulties met with in using this element, there is a possibility that the resulting glass would change under the action of light.

The coloring compounds used in the daylight glass which forms the subject of this paper are all fast colors, if we may be allowed to use that term in this connection, and suffer no change whatever. The colors are added to the batch in the proper proportions, having regard to the final thickness of the finished pieces, after which the thickness for which the coloring was calculated must be adhered to.

Owing to the constancy in thickness required it will be very difficult, if at all possible, to blow satisfactorily globes of this glass, consequently all samples yet produced are pressed.

The percentage transparency of the three coloring constituents is shown in Fig. 3. They do not happen to be the relative concentration used in the glass, so that multiplying the ordinates together will not produce the transparency of the finished glass. The absorptions are such that by manipulating their relative concentrations the glass can be adopted to the ordinary gas mantle light, the 1.25-w. p. c. tungsten or the high efficiency gas-filled lamp, all of these producing artificial daylight.

In the case of the gas lamp, by substituting for the ordinary mantle a special one having a smaller percentage of ceria, we can with the same glass obtain a blue sky color.

A considerable part of the time spent upon the investigation was devoted to the development of a method of successfully making, handling and annealing glass on a small laboratory

scale quite apart from the question of color. In fact the making of colored glass was not attempted until the underlying problems were solved. These were two in number—the selection of a pot which would be absolutely free from iron oxid, or other impurities that would have a tendency to color the crystal glass, and the successful production of flat disks of glass that would not crack during grinding.

The pot question was a serious one. After an unsuccessful effort to make our own pots and to have special pots made for our requirements, we finally decided upon an imported unglazed French clay crucible. These gave entire satisfaction, and although some of them contained iron it was in such form that its presence could readily be detected and the crucible discarded. The pots were kept in an oven at a temperature of say, 500° F. for twelve hours previous to being placed in the furnace, after which they withstood any temperature required in the glass making.

As each pot could be used but once, due to the impossibility of completely removing the colored glass, a small size pot had to be selected. This was the No. 7, holding one third of a pound of glass batch, sufficient to make a disk 7 cm. diameter and several mm. thick.

When the pot difficulties were solved a large number of glasses having various compositions were made. Among these were soda lead, soda lime, potash lime, potash lead, potash barium, and these standard glasses were varied by adding borax, oxidizing agents, reducing agents, etc.

Before the work continued long, however, it was discovered that black Ni O in a glass containing potash and barium gave a color which looked very promising as one of the constituents in a daylight glass. Further investigation along this line showed that the potash was absolutely necessary to the production of this color and that otherwise the composition of the glass made very little difference. The effect of the potash will be seen in Fig. 7. The potash glass which gave curve 1 was a very clear purple, while the soda glass containing the same nickle oxid, the curve of which is shown in 2, had a dull brownish tinge,

absolutely unsuited for the purpose. A potash barium glass was then adhered to.

The work was carried on in a battery of five gas furnaces. They were designed and built in a laboratory and were heated by carbureted water gas having a heating value of 650 B. t. u.'s per cubic foot, the air being supplied at a pressure of 2 lbs. and the gas at 2 in. (5.08 cm.) water column.

Before the air reached the burners it was passed back and forth over the hot products of the furnaces. This increased the efficiency of the furnaces considerably and shortened the time of working. This preheating device could be lifted back out of the way to facilitate the removal of the glass samples. It was possible to attain a temperature of 3,000° F. with the preheating device in use, although a working temperature for most of the glass was about 2,500° F.

The furnaces were lined with a mixture of alundum grain and cement in the proportion of 2 to 1, respectively.

The pot was taken from the drying oven and placed in the furnaces in the morning and allowed to heat up with the furnaces. When it became red hot about one third of the batch would be added. This would fuse in about 15 minutes and the procedure would be repeated until all of the batch was in the pot when it would be allowed to stand for 6 or 7 hours at a temperature between 2,000° F. and 2,500° F. when the glass would be sufficiently "fined" to mold into disks.

At the beginning in making these disks the glass was poured from the crucible onto a flat iron block, which was kept quite hot, and the whole then placed under an ordinary arbor press and pressed into flat disks. When these were sufficiently hard to withstand handling they were smothered in cotton, a method of annealing that has long been used by glass blowers. This annealing was not sufficient, however, for the thicker pieces and the following method was adopted and adhered to.

Instead of pressing the glass it was dropped into a depression in a cast iron block at a sufficient temperature to make the glass acquire a level surface on top. After a few minutes these blocks were turned upside down and the contents dropped into a sand bath. This bath was placed over one of the furnaces so ad-

justed that the sand in the bottom was red hot when ready for use. A sample was then dropped down a central tube, the tube partly removed to allow the sand to collapse upon the sample, when it was ready for another one. In this way the various samples could be distinguished from one another upon removal. This operation would take place about 5 o'clock in the afternoon. By 9 A. M. the next day, after an unrestricted drop in temperature, the sand bath would be about 200° F. when the sample would be removed. This is not a slow drop in temperature, but it was sufficient to prevent the glass from cracking during the grinding and polishing which followed.

When the time came for applying the knowledge gained in the laboratory to the work in the factory more difficulties were encountered. It was found that the potash barium glass was not easily worked and that it was almost impossible to successfully press large disks of this glass. It was quite infusible and contained "seeds" which were impossible to remove. Experiments had to be then carried on with the view of substituting lead for barium, pound for pound. This effort was successful and after allowing for increased specific gravity very little color change was noticed in the lead glass, provided the potash was present.

The impurities in the pots and the slightly impure materials which must of necessity be used when working on a large commercial scale lowered the accuracy of the laboratory results.

A possible source of error was the coating of glass left in the pot when changing from one color to another. The method adopted in overcoming the above difficulties will be explained later.

Another difficulty was the accuracy in thickness with which the glass had to be pressed. Five per cent. change in thickness would change the daylight value considerably. As the disks were 5.4 mm. thick, a tolerance of 5 per cent. would be equivalent to $\frac{1}{4}$ mm. or $^1/_{100}$ in. This is a degree of accuracy unusual in the art of pressing glass and it called for special care on the part of the workmen. They rose to the occasion, however, and before many attempts were made we were turning out glass of the correct thickness.

To overcome the first difficulty mentioned above, it became

necessary to make three large batches of glass in the ordinary factory pots, maintaining factory conditions throughout. All of these melts were made in the same pot, the pot having been washed out with crystal glass between melts and then twice with small quantities of the new batch. Each pot was colored with one of the constituent oxids to a concentration that was approximately a mean of anything that would be required for any of the daylight glass to be developed.

From each pot there was made a couple dozen blanks 2.5 in. (6.35 cm.) $\times$ 0.5 in. (1.27 cm.) thick. These blanks were ground and polished to various thicknesses, advancing in steps of about 10 per cent. These were spectrophotometered in various combinations and when the proper combination was selected, knowing the thickness and the concentration, the new concentration for the final thickness could easily be calculated. Coloring mixed according to this calculated formula was then sent to the factory and another large batch made. Samples were ground and polished to the thickness previously decided upon and spectrophotometered. The few changes in the spectrophotometer curves were within the experimental error.

A product that is to maintain the color value of a light up to the standard of average daylight must have some primary standard of white light as a basis to which it can be referred. To make this possible there has been developed at the laboratory an apparatus for the spectroscopic synthesis of color.[3] It is shown in Fig. 8. A brief description of this instrument will not be out of place at this time.

If, for the photographic plate of a spectrograph that is properly adjusted and in focus, we substitute a magnesia oxid surface S^1 illuminated by a 4-watt lamp, an eye placed at the slit S will see the face of the prism P illuminated by 4-watt color. Each element of the surface S^1 emits waves of all length within the visible region, but only those waves having the right length to be refracted into the slit S reaches the eye, all others being absorbed by the blackened lining of the instrument. Hence the 4-watt color at the eye slit.

If between the prism and the magnesia surface and close up

[3] Ives, Herbert E., and Brady, E. J., An Apparatus for the Spectroscopic Synthesis of Color; *Journal af the Franklin Institute*, July, 1914.

to the latter there is placed a rotating sector disk, with suitable openings, the character of the light entering the eye slit S from the magnesium surface can be altered to any desired spectral composition.

With the use of a disk with openings so calculated that the light entering the eye-slit S^1 is equivalent to a black body at 5,000 deg. abs. This then is an absolute and unvarying standard for the daylight glass. It is a standard that is reproducible anywhere, and is independent of any local atmospheric conditions.

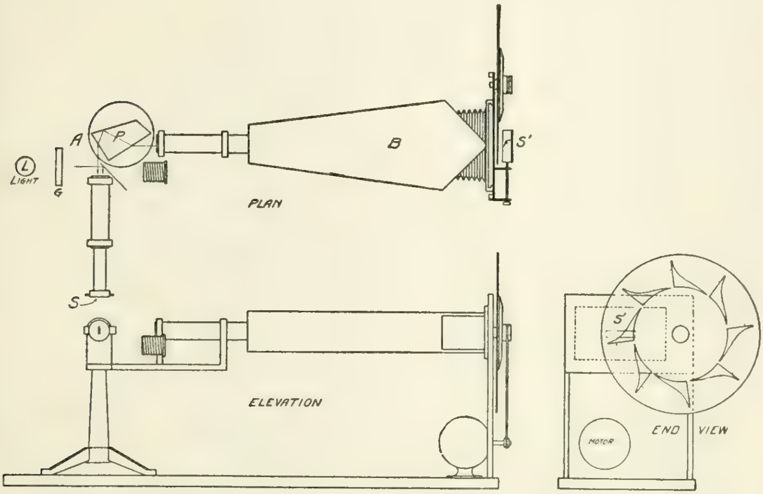

Fig. 8.—Sketch of apparatus for producing by means of a rotating sector, any spectral energy distribution required.

The next problem is to maintain the product of the factory up to this desired standard. Absolute perfection is, of course, unattainable. Certain tolerance limits outside of which the glass would be rejected must be established. Spectrophotometric measurements at the factory would be costly and impracticable.

There are three variable factors that a tolerance instrument must measure: First, the color may be off, due to the improper proportions of the various coloring oxids; second, the relative proportions may be correct, but the total concentration of the colors may be high or low, and third, the thickness of the in-

dividual pieces of glass may be incorrect, this latter having the same effect as changing the concentration.

An instrument that is suited to measure all of these factors in a very simple manner was devised. It is shown in Fig. No. 9, and consists of three disks of colored glass, each disk being of a known thickness and colored by one of the three component oxids that enter into the composition of the completed glass. These are mounted as shown in a box with a lens at one end. A

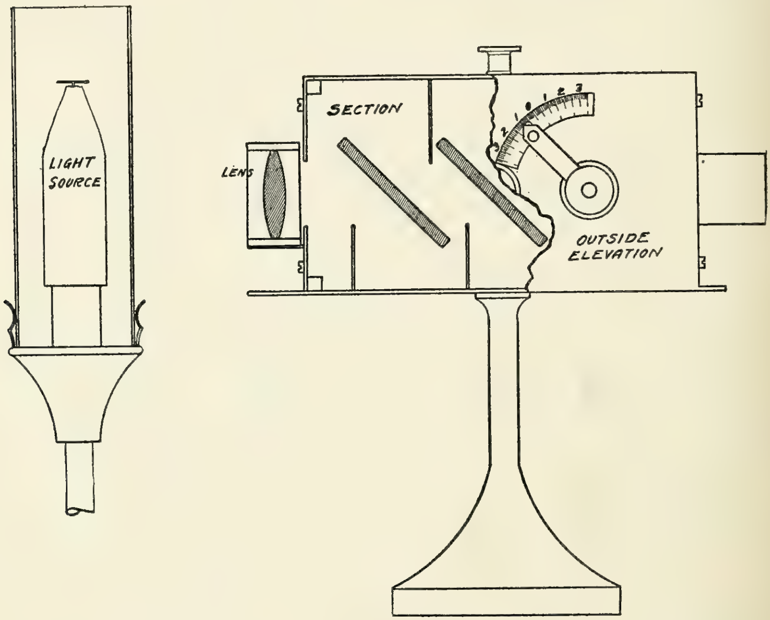

Fig. 9.—Tolerance instrument for determining departure from the standard.

parallel beam of the light for which the glass is being made is directed through these disks and falls upon the comparison surface of the synthetic apparatus as shown at "G" Fig. 8. Each of these disks is capable of being rotated independently about its diameter and the angular position of the disk is shown on the scale on the outside of the box, as shown. These scales can be calibrated in percentages of the standard thickness. The standard thickness being the length of the light path through the glasses when they are placed at a known angle, makes it possible to measure concen-

trations that are less than the standard. If, after a color and intensity match is obtained between the light passing through the freshly-made glass under test and the tolerance instrument is obtained, the three scales, read, say, + 4 per cent., then we know that the relative concentration of the three colors is correct, but either the concentration or the thickness of the piece under test is 4 per cent. too great. It will readily be seen that an excess or deficiency of any one coloring oxid can also be detected in a similar way. The thickness of the three glasses is made such that all the scales read zero when matched against the synthetic apparatus before leaving the laboratory. It is to be borne in mind that the daylight

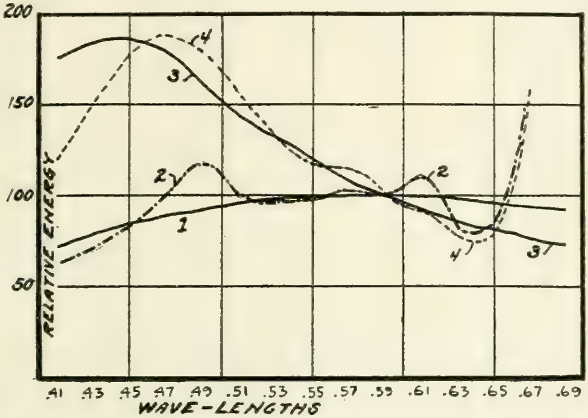

Fig. 10.—Curve showing energy distribution of the daylight glass, and how a blue sky effect can be obtained with the same glass by simply changing the mantle. 1. Average daylight. 2. Daylight glass using ordinary Welsbach mantle 0.75 per cent. ceria. 3. Blue sky. 4. Daylight glass using special Welsbach mantle 0.25 cent. ceria.

quality of the glass is not dependent upon this instrument. The daylight quality has been determined wholly by the spectrophotometer in the laboratory during development. This instrument is to be used in the factory and its function is to hold the integral color of the glass constant.

In Fig. 10 is shown the energy distribution of the artificial daylight as obtained by the use of the new glass and the Welsbach mantle compared with the distribution of average daylight and blue skylight.

The departure from the ideal in certain parts of the spectrum, as shown by the curves, is relatively small.

In Fig. 11 is shown the energy distribution curve of an entirely different glass which has been developed for use with a gas-filled tungsten lamp, operated at 0.65 w. p. c. This curve has about the same departure from the ideal as the one shown in Fig. 10. Substantially the same curve can be obtained from the 1.25 w. p. c. tungsten lamp, provided the glass composition is made for that source, and it might be well to lay stress upon the fact that each illuminant requires a different glass.

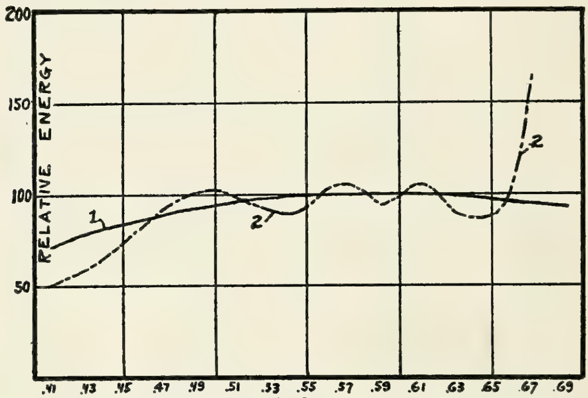

Fig. 11.—Curve showing energy distribution through a glass that has been developed for use with the nitrogen-filled lamp. 1. Average daylight. 2. Daylight glass using type C. tungsten lamp at 0.65 w. p. c.

The ultimate criterion of any daylight glass is not the spectrophotometer curve, but its color-matching quality. Colors which were extremely susceptible to a change in appearance under artificial light were viewed through these glasses and the appearance was the same as under daylight.

During this research nearly all the known coloring compounds were tried, but before the work progressed far most of these were eliminated. About two hundred different meltings were made.

The author is indebted to Dr. Ives for suggestions during the laboratory work and to Mr. James Gillinder, Jr., who had charge of the work in the factory.

DISCUSSION.

Mr. E. B. Rowe: The fact that several papers have involved artificial daylight or, rather, a criterion for daylight, average daylight, blue skylight, and so on, as Mr. Pierce pointed out leads me to suggest that this is one of the things which the Research Committee could look into during the coming season and, if proper, make recommendations to the Committee on Nomenclature and Standards, so that we may have something that everybody can agree on. There is not, perhaps, a very great variation between the different daylight standards, and therefore we ought to be able to agree on some one standard which different observers and investigators can adopt. There will then be less excuse for certain discrepancies which may unwittingly creep into different papers.

The permanency of these color-correcting units, which was touched upon in this paper, is of course, very important. We have seen in some cases how ordinary window glass changes under the long continued action of sunlight. There should be some assurance that any commercial units which are put out are fairly permanent in their color correction.

This paper is rather unusual in the manner in which the subject is taken up and I am particularly glad to note that the details of a factory testing or "tolerance" instrument, as it is called, are given here, because careful inspection and testing are important features in the commercial marketing of any glassware of this sort, to insure that the factory output is uniform.

Dr. H. E. Ives: I would like to merely add a few words to what Mr. Brady has said in regard to the practical character of this glass. It was necessary in developing a glass of this character that the constituents should be such that they could be tested out in the laboratory one by one, the result of their combination predicted and then worked out. But more than that, it is necessary, to have a product which will be uniform in one place and another, from one time to another, that the glass shall be turned out every time exactly the same and that it shall not change.

I may perhaps tell a personal experience on this matter. Several years ago I was working on this same problem and I

told the glass factory which was associated with the people with whom I was then employed, that a combination of copper, cobalt and gold would make a splendid artificial daylight glass. Their answer to this after a few days was to send me half a dozen disks of glass colored by gold. They had had exactly the same heat treatment, the same annealing, were of the same thickness and varied all the way from colorless glass to a deep red; consequently, to produce the kind of glass we have in mind here, gold was out of the question. Manganese and copper would make an excellent glass, and by taking separate pieces one could get something really admirable; but every piece of manganese glass is different from every other, so this proposition of making a uniform glass, one disk like another, was ruled out.

I think we have here a glass that can be turned out day after day, one day after another, every piece perfectly uniform and of guaranteed character. In discussing this or that glass and its relation to a previously selected curve, we must remember that other considerations enter in very largely, such as the question of practicability, and that this glass is eminently practical. The great novelty of this glass lies in the use of nickel oxid in a potash glass. The blue and green constituents are well known coloring materials, but hitherto the only purples used in this connection have been the unreliable gold or manganese. As far as I can find, and as far as the Patent Office can find, the use of this reliable nickel glass is quite new in this connection.

Mr. F. E. Cady: There is so much valuable information given on the way this glass is manufactured, in this paper, that it seems to me it would be helpful if Mr. Brady could add to it the absorption of the glass, that is the reducing effect in lumens per watt for both the Welsbach lamp and the tungsten lamps.

Dr. H. P. Gage: I have very little to add to the discussion of this paper. Mr. Brady has taken up the practical difficulties which have had to be solved by the glass maker and gives, I know, a very good idea of what those difficulties are and what is necessary to overcome them. He has worked along the line of getting what coloring is necessary into one glass and having these colors such that one can depend on getting the melts the same from time to time. Except for the violet and red ends

of the spectrum, Mr. Brady has gotten a good approximation to the desired spectrophotometric curves, probably as good as could be obtained in one piece with the glasses and coloring materials with which Mr. Brady worked. Better results might be expected if a greater number of glass making materials had been investigated. Dr. Ives and Mr. Brady are to be complimented on the instruments which have been devised for testing the glass and for securing uniformity in the product.

MR. C. O. BOND: If investigation shall prove that this artificial daylight, either Mr. Brady's or Mr. Luckiesh's or any other, is on an equality with true daylight in the distinctive quality which is necessary for good seeing, then we have here a criterion by which we can compare other artificial lights in laboratories or elsewhere. Would it not be well worth while for someone to undertake a complete installation in some building with a glass for producing artificial daylight such as this does, and to run it for a year, keeping illumination data, and let us see what practical answer is given by the people who live under it and do their work by it. It is an expensive installation, as to current, but we should know the truth about the value of the daylight quality.

MR. J. R. CRAVATH: We must remember, if we try any such experiment as President Bond suggests, that we are dealing with a number of very distinct elements. Artificial light differs from daylight not only in color, but, as we ordinarily use it, in direction and diffusion. If you vary only one of those elements at a time, all right, but when you are varying all three of them, I fail to see how you are going to find out much by any such practical experiment as has been suggested. We must have some way of eliminating the other variables in our tests; which can be done but it is not easy. It seems to me that a great deal too much emphasis has been laid sometimes on differences in color, although I do not say that color is unimportant. In the case of daylight coming through windows, we have light coming from one side, from comparatively large areas. The brightness of the surfaces from which we are receiving the light is comparatively low, that is, as compared with artificial lighting where we get the light

* Luckiesh and Cady, Artificial Daylight: Its Production and Use; TRANS. I. E. S., vol. IX, p. 839.

direct from the lamp or a small diffusing envelope. We must come to an exact analysis, not only of color conditions, but of direction and diffusion.

MR. G. H. STICKNEY: The author has mentioned two factors entering into the quality of light for color matching: intensity and color. The most accurate color matching is required in dye rooms of textile mills. I have found diffusion is also an important factor, in that it seems to determine in some degree the depth to which the light penetrates the fabric, and thereby the apparent color of the material.

With regard to the practical applications—the practise seems to be hardly well enough standardized to be thoroughly described. The most exacting demand that I have met with is in the dye rooms of high-grade textile mills, where an accurate illumination of an intensity of about 35 foot-candles seems to be required. The area to be lighted, however, may be relatively small.

Color matching light is also sometimes required for perching. This process, among other things, requires the inspection of the evenness in which a piece of cloth is dyed. A lower intensity of light, say 15 to 20 foot-candles, depending on the color of the material, is likely to be satisfactory. The area to be lighted is somewhat greater than in the dye room.

For general lighting in certain departments of dry goods stores, approximate color matching light is desired. It is usually found impracticable to supply much over 6 foot-candles. The accuracy of the light need not be of the same order as that required in the textile mill.

In industrial processes there are a number of conditions in which the intensity to be required, the area to be illuminated and the accuracy of the illumination all vary. Plain units are ordinarily satisfactory, whereas in dry goods stores, ornamental units and pleasing lighting effects are demanded.

MR. JAMES P. HANLAN: We all believe there is a market for daylight glassware. As the last speaker has stated, the glass will have to be enclosed in a suitable covering so that it will be pleasing to the eyes of not only storekeepers, if it is used for purposes of store lighting, but also to the eyes of their customers. Those of us who are out in business actually trying to sell illumin-

ation hope that this glassware is perfected so that it can be available for commercial use, as it will be a great help to us.

Use has already been found for a glass which produces a "daylight" effect; many of Dr. Ives' daylight producers have been installed in dyeing establishments. In the course of a conversation the other day with Mr. C. A. Luther, the illuminating engineer of the Peoples Gas Light & Coke Company, Mr. Luther mentioned the fact that his company had made a number of installations of an arc lamp the company is selling called the "daylight gas arc" in stores and factories where it is desirable to have a light source that approximates daylight. I believe the lamp is equipped with daylight mantles.

MR. WARD HARRISON: The point of view which appeals to me most strongly is that taken by Mr. Stickney regarding the practical application of these developments. I am of the opinion that before any extended use is made of this glassware in store lighting, for example, the units will have to be put up in such form as to appeal to the artistic sense and to present as good an appearance as is now shown by the usual store lighting units. To accomplish this, it will probably be necessary to enclose the colored globes in an envelope of some kind which will conceal the bluish tinge in the glass when the unit is not lighted. We have found that in the majority of cases the blue glassware seems decidedly displeasing to the average observer and particularly so to the manager of the store.

MR. NORMAN MACBETH: There are one or two points brought by those who have discussed this paper with which I am not in agreement. In this matter of the color of illuminants in stores, I think Mr. Harrison will bear me out that there are thousands of enclosed arc lamps in use to-day because of the color of the light. I believe that this color loyalty to the old lamps is largely psychological, and that the displacing of them is largely a matter of salesmanship. You need only satisfy your storekeeper as to what this color filter incandescent unit will do for him.

References are constantly being made to standard sunlight and standard daylight. We are far from any agreement on such standards. I do not know whether it is within the function of any committee of this society, but it certainly ought to be within

the scope of the Bureau of Standards to fix such standards. We have an international candle-power unit and I think we should also have an agreement on a standard daylight. Not so long ago, we had all kinds of candle-power; now we have one international unit. This paper by Mr. Brady mentions the comparison with a black body at a temperature of 5,000 deg. absolute. It should not be difficult to secure agreement on this point. The various glasses available for use could be standardized in some such place as the Bureau of Standards. Sunlight, daylight, north sky, etc., could then be given a definite meaning. When we get colors that will match under sunlight and will not match under blue skylight, that will match under daylight and not under artificial light, that will match under a peculiar color of artificial light and not anywhere else, we surely have a problem on our hands. The entire question, however, is not so much one of color matching but of color identification. I have known of a number of instances where materials have been bought under daylight, and cut up and put together for gowns under artificial light. In one case where the fitting was arranged under artificial light, the woman said, "That isn't my material at all, that stuff doesn't match any more than black and white; I had chosen a pleasing color combination." The material was taken back to the store where it had been purchased; it mached under daylight, not an artificial daylight, and the color scheme was pleasing. In talking not long ago to a lady who runs a large costuming establishment, she told me that the difficulty was in getting materials that would match under artificial light as well as daylight. I know tailors who are putting out dress suits of a dark blue material under daylight, that is black under artificial light.

It seems to me that if we are going to do anything with this artificial daylight that, in view of the history back of every new illuminant that has been heralded as producing white light, we should have some certification available, which will indicate the aniline dyed materials used and the extent to which they appear differently under various kinds of light.

MR. WARD HARRISON: If I might correct a misimpression which I think Mr. Macbeth and possibly some others gained—I did not mean that the color of the light was objectionable; I

think it is highly desirable in a great many cases. When the lamps are turned off, however, most of the globes present a decidedly blue appearance, and in very few cases do they harmonize with the general color scheme of the store. If the blue globes could be placed inside of an opal or similar envelope which would take away the blue tint when the lamps are not lighted, I think we would find them more generally acceptable.

MR. G. H. STICKNEY: I agree with Mr. Harrison that certain color screening globes would be likely to make an objectionable appearance in a store. It is important to consider the appearance of the fixture when unlighted as well as when lighted, and I believe that a bulb with an opal flashing would be much more acceptable to the store manager than one that appears dark blue when unlighted.

MR. EDW. J. BRADY (In reply): Mr. Rowe mentioned the permanency of the color of the glass. These colors are all very permanent. The glasses that I showed you were made, partly of batch and partly of cullet, that is old glass melted over two or three times. These globes that I have shown you could be broken up and re-melted again and the color would be exactly the same. The lack of permanency is more particularly in connection with the use of manganese or gold. It is very difficult to work and you really cannot tell what you are going to get. Dr. Ives mentioned the difficulty of working gold. Well, from the work I have done upon gold, I can certainly emphasize his remarks; it is very, very difficult to work, and to attempt to work it in connection with other colors and to turn out glass of a constant concentration is practically an impossibility.

A question has been raised as to the use of this glass—why, I don't think there are many of us who really appreciate the extent to which this glass could be used if people found out there was such a thing on the market.

Mr. Stickney mentioned the third factor in daylight, the question of diffusion. That is a question of the design of the fixture and not of the quality of the glass.

Mr. Gage said he thought this was a very good curve for the extent of the investigation. Although I have made a large num-

ber, still I appreciate the fact that I only touched upon the subject of glasses; I confined myself to the production of a daylight glass.

The chairman touched upon the question of the amount of light that might be required in using the new artificial daylight. I think that question is an important one; one that is worthy of an extended investigation. We speak of the efficiency of a light source in terms of lumens per watt or lumens per B. t. u., leaving the continuous use of the eye as a working instrument out of consideration. We know that the sensation of color is a function of the energy distribution of the light source. May not the sensation of fatigue or eye strain be also a function of that distribution? May not the presence of the long red waves in ordinary illuminants have a quenching effect upon the sensation producing power of the green and blue waves? This new daylight glass furnishes a means of investigating these problems.

RECENT DEVELOPMENTS IN INCANDESCENT GAS LIGHTING.*

BY ROBERT FFRENCH PIERCE.

Synopsis: After classifying the opportunities for improving incandescent gas lighting units, the author calls attention to the fact that, while careful and exact studies of the mantle have been made, little attention has been given in the past to the development of burners, which has followed along lines of "cut and try" methods. About two years ago the first serious research on the bunsen burner, as applied to gas lighting, was begun and this has shown that slight modifications in the design have a very distinct bearing upon the effectiveness of the burner. The author describes the improvement which has resulted from such investigation, giving new figures which show a saving in the cost of gas lighting of 50 per cent. in favor of this new burner as compared with older units.

Under the head of improvements come for consideration developments bearing upon—

I—Initial efficiency of light production.

II—Deterioration from initial efficiency and light output, either
- (*a*) inherent or
- (*b*) resulting from the factors usually embraced (more or less intelligently) under the head of 'practical operating conditions.'

III—Maintenance.
- (*a*) Time.
- (*b*) Labor.
- (*c*) Convenience.

IV—First cost per unit capacity as determining fixed charges, viz.:
- (*a*) Interest on investment.
- (*b*) Depreciation.

V—Flexibility in adaptation, interchangeability of parts, etc.

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

COMPLETE INCANDESCENT GAS LIGHTING UNITS.

In the case of incandescent gas lamps, it is highly desirable to separate the permanent and the renewal elements, since each independently influence the performance of the unit from all standpoints. The necessity of this procedure is particularly apparent in considering depreciation due to obsolescence. In the case of an electric incandescent lamp of say 250 watts, the permanent element is the socket, costing say 11 cents, and practically not subject to deterioration or obsolescence. In the case of an incandescent gas lamp of corresponding capacity, the cost of one type of burner, which is the permanent element, is say $12.00. In the case of the electric lamp, the permanent part is practically negligible as regards the continued performance of the unit; in the case of the gas lamp, it is highly important.

BURNER AND ACCESSORIES.

The burner is composed of a gas orifice, air ports for the admission of primary air, a race-way and mixing chamber (the latter fitted with a gauze or a thermostat), a nozzle and a suitable housing or shell.

The gas orifice determines, by its form and size, the velocity and air-entraining power of the incoming jet. It therefore influences initial efficiency and, if subjected to fouling, subsequent depreciation.

The race-way, mixing chamber and nozzle are the most important factors in the design of incandescent gas lamps. Their relative dimensions and form control initial efficiency, and the gauze or thermostat, if subjected to fouling, may be responsible for a considerable deterioration.

Accessories.—The glass cylinder or chimney which is the only accessory necessary to the performance of the present type of lamp is also of much importance; its size, form, design, number and dimension of air-holes, etc., have a considerable influence on initial efficiency, while deposits of dust or combustion products may produce considerable deterioration under service conditions.

A test to determine and separate the deterioration due to the above factors and reported by the writer[1] showed that under the conditions of test the burner proper was responsible for a de-

[1] TRANS. I. E. S., vol. VII, p. 677.

terioration of say 2½ per cent. per 1,000 hours, and the cylinder, say 10 per cent. The conditions of test were as nearly as possible like those of actual service in which ordinarily clean gas of commercial quality is furnished at constant pressure. The air was very highly charged with particles of mineral matter, and the fouling of the orifice was undoubtedly much greater than would occur under any but the most extreme and unusual cases in actual practise.

There were no gauzes in the mixing chambers, but a somewhat similar device known as a "distributor" having a similar effect was used. This device consists of a band of deeply corrugated metal bent into circular form, the axis of corrugation being parallel to the axis of the chamber. In one case the advent of a plague of mosquitoes resulted in the fouling of the distributors by their charred bodies, and produced a reduction in candle-power of about 20 per cent. This simply indicated the desirability of using air-port screens—a commercial device fitted to the lamps when ordered—and obviously bore no relation to the ordinary performance of the lamps. There were a few cases of carbonization, the candle-power depreciation amounting to from 20 to 25 per cent. It must be borne in mind that no adjustments were made upon those lamps for the period of test, and in this respect the conditions were more severe than those of actual service.

Carbonization is usually an indication of excessive fouling of orifice or mixing chamber, or of the inability of the gas to entrain sufficient primary pair to produce a non-luminous flame. Carbon trouble from the latter source is usually confined to inverted lamps—those in which the entraining jet is directed downward—and may be corrected by adjustment. The upright gas lamp will operate without adjustment over a much wider range in gas conditions than the inverted, because the better entrainment which provides a higher margin of primary air above the carbonizing point. From whatever cause carbonization may arise, its frequency and extent is greatly reduced by increasing the entraining power of the gas jet, at the orifice.

Mantles.—The tests mentioned above indicate that the deterioration in light output of the artificial silk mantle is in the neighborhood of 2½ per cent. per 1,000 hours, and among the 12

mantles used in the test, no failure or breakages occurred during the entire period of 5,000 hours.

The inverted mantle by reason of the manner of support is far more rugged and durable than the upright type.

There has been, and is being a great deal of money expended upon research work in connection with gas lighting appliances. Heretofore, work of this character has been largely confined to the mantle. The reason for this is obvious: The initial difficulties were so apparently overwhelming as to bring an early realization of the fact that technical talent of a high order, and research and investigation of the most painstaking and extensive character were absolutely essential to the development of incandescent gas lighting beyond the status of an interesting laboratory experiment. In fact, in the development of no other lighting appliance have the obstacles encountered and overcome been so formidable and refractory as those met in the development of incandescent gas lighting. From this standpoint it is by far the greatest achievement in illumination, ancient or modern.

On the other hand, the burner was of such apparent simplicity of design as to be considered scarcely worthy of attention. Recently, however, a reversal of position was seen to be necessary. The substances available for use in the mantle, and the manipulation necessary to ensure the highest quality of product appear to have been so thoroughly explored and investigated that the direction of future developments in efficiency, permanence and mechanical strength is not even indicated.

Until the last two years little was known of the behavior of gas and gas and air mixtures in the bunsen burner. Not even empirical formulae for burner design existed, and the development of a new burner was a cut-and-try process, the best combination being selected without any knowledge as to whether a better one might be possible. Occasionally an exceptionally efficient burner was developed, but the reasons for its efficiency were so little understood that it was often impossible to even approximately duplicate the performance in other sizes. The general opinion prevailed that the inverted burner was inherently superior to the upright in efficiency, while as a matter of fact quite the reverse is the case, and the apparent superiority of the

inverted burner was due to causes entirely unrelated to the burner itself.

About two years the first serious research work on the bunsen burner as applied to gas lighting was begun. The difficulties in the way of securing positive knowledge concerning the processes carried on in the burner are numerous. Direct quantitative measurements of the principal quantities involved are extremely difficult with any of the means available at present. The forces and masses involved are indefinitely small and the results of their interactions cannot be forecasted successfully by deductive methods.

In the line of investigation undertaken it was attempted to establish certain observable criteria of burner performance which might be taken as at least indicative of the effects desired.

Orifice.—The object of the orifice is to permit the outflow of gas under conditions favorable to the maximum entrainment of and most uniform admixture with the primary air. The first investigations were conducted upon the orifice alone without raceway or mixing chamber. Surrounding the gas stream by vapor of ammonium chlorid offered a simple means of observing its behavior. It was found, however, that the form of stream when lighted at the orifice presented the same appearance as when unlighted and defined by vapor. Tests of actual burners also indicated that this criterion was a sufficiently useful one for practical purposes, and it was adopted for the preliminary investigation of orifices.

Tests of several complete burners in conjunction with observations of the lighted gas stream from the bare orifice indicated that the most desirable jet is one which when lighted presents the smoothest flame surface and produces the least noise and the longest and narrowest pencil of flame. Unexpectedly enough the best orifice for this purpose was found to be a small circular hole in a very thin check, although deductive reasoning would indicate that since entraining power varies as the square of velocity, it should vary as the square of the efflux coefficient of the orifice. It was found, however, that this form was suitable for only very small orifices. In larger orifices the annular form

appeared most effective up to certain limits, beyond which a plurality of small orifices were required.

Race-way and Mixing-chamber.—Having determined the most suitable form of orifice, the race-way and mixing-chamber were investigated. This investigation was necessarily of an empirical nature. Preliminary investigations were based upon the size and color of the flame cone at the nozzle, this being an accurate indication of flame temperature.

Although it has been known for a long time that the dimensions and forms of these parts greatly influenced the performance of the burner, the tremendous influence of apparently insignificant modifications was most surprising. It would not be feasible to enter at this time into an extended discussion of the essential features of burner design as developed by these investigations. The experiments have, however, progressed to a point where the necessity for extreme refinement in design has become apparent, and the fundamental and essential features of race-way and mixing-chamber design have been clearly indicated. These are as follows:

1. The gas jet issuing from the orifice should be discharged along the axis of a straight raceway, the diameter and length of which will depend upon the quantity of gas flowing. 2. The race-way should discharge into the mixing-chamber by a suitable taper. 3. Means should be taken to further the intimate mixture of air and gas by utilizing a portion of the kinetic energy of the mixture in such a manner as to promote thorough mixing. 4. The formation of eddy-currents, or the useless absorption of the kinetic energy of the gas-and-air stream is to be avoided.

The first and second features are necessary for the most effective entrainment of air and the delivery of the gas and air into the mixing-chamber at maximum velocity.

The third and fourth requirements present the more difficult problem, and play the large part in the final result. In the present or ordinary type of burner, there is more or less stratification in the air-and-gas mixture, diffusion alone being insufficient to produce more than a very imperfect mixture. The limit of air entrainment and hence, the flame temperature, is therefore fixed by the most fully aerated stratum of mixture. This appears to

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Fig. 1.—A recently designed gas lighting fixture.

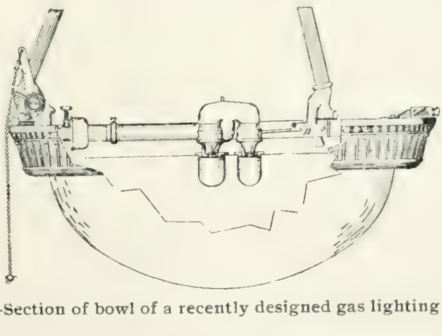


Fig. 2.—Section of bowl of a recently designed gas lighting fixture.

be responsible for the low efficiency, sensitiveness, and occasional noisiness of the ordinary type of burner. On the other hand, if uniform mixture be effected by means which too greatly decrease the velocity with which the mixture is delivered from the nozzle, the limit of air entrainment is restricted to a comparatively low figure by the rate of flame propagation in the mixture.

The real problem, therefore, has been to secure thorough mixture of gas and air with the least sacrifice of kinetic energy. In fact, the principal problem of burner design may be said to be one of kinetic energy. The results so far secured are,

1. An increase in efficiency of from 50 to 100 per cent. depending upon the size of the unit. 2. The entire elimination of the necessity for enclosing glassware. 3. A burner which is practically non-carbonizing and noiseless under the most extreme conditions, and in which the effects of fouling are negligible. 4. Very inexpensive construction of such flexibility that practically no limit is placed upon the design of fixture, and the capacity of units may be easily altered by the changing of simple and inexpensive parts.

The revolutionary nature of this development is clearly apparent. The most serious disadvantages under which the incandescent gas lamp has labored have been,

1. Excessive deterioration in light output due largely to the narrow range in gas conditions over which a given adjustment could operate, a comparatively small variation in one direction producing carbon, and in the opposite direction noise or "flashing back." Small accumulations of dirt either in the orifice or gauze produced the same effects as those changes in gas quality which were responsible for carbonization. 2. Necessity for frequent attention, due to the operation of above cause. 3. Fouling of enclosing glassware. 4. Excessive initial cost of permanent parts. 5. Lack of inter-changeability of parts of different units, and lack of adaptability to the requirements of fixture design.

The elimination of practically every factor entering into deterioration in light output and efficiency leads one to believe that the laboratory performance will be approximated in actual practise and throughout the mechanical life of the mantle.

The following table gives some of the more important comparisons between the old type of burner and the new.

OPERATING COSTS PER 1,000,000 LUMEN-HOURS.
Units of 200 M. H. CP. (Approximate.)

	Hours yearly	Old type 200 lm. per cu. ft. cons. 4 cu. ft. per hr. per mantle; price, mantle 35¢ each; burner $12.00 per 200 cp. capacity	New type 363 lm. per cu. ft. cons. 2.5 cu. ft. per hr. per mantle; price, mantle 20¢ each; burner $2.00 per 200 cp. capacity	Saving New type over old Per cent.
Gas in cu. ft.		5,000	2,750	65
Mantles based upon 1,000 hrs. life		$0.44	$0.22	50
Burner depreciation at 25 per cent. yearly ...	500	2.50	.36	
	1,000	1.25	.18	
	2,000	.63	.09	
	3,000	.42	.06	
	4,000	.31	.045	80.6
Cost of pilot lights; cons. 0.1 cu. ft. per hr. each burning continuously; gas @ $1.00 per M cu. ft.	500	.72	.64	
	1,000	.36	.32	
	2,000	.18	.16	
	3,000	.12	.11	
	4,000	.09	.08	11

The net saving per 1,000,000 lumen hours of the new type over the old in burning 1,000 hours per year with gas at $1.00 per M is thus:

	Old	New
Gas	5.00	2.75
Depreciation	1.25	0.18
Renewals	0.44	0.22
Pilots	0.36	0.32
	7.05	3.47
Saving..................................		50.8 per cent.

It is quite unfortunate from a commercial standpoint that the new type of lamp, which cuts operating costs in half, cannot be given a distinctive name based upon some new principle of material involved in its production, in view of the fact that it parallels in the gas lighting field the position of the nitrogen-filled tungsten lamp in the electric lighting field, except that the former is available throughout the entire range of commercial sizes.

The saving in energy and material costs is, however, by no means the most important advantage of the new type.

Dispensing with the chimney eliminates a deterioration in light output of at least 10 per cent. per 1,000 hours, as well as the expense due to chimney breakage.

The wider range of operation without readjustment and the use of a gauze of such wide mesh that no reasonable amount of fouling can affect the efficiency of the unit, makes a great reduction in maintenance labor—the greatest handicap upon gas lighting. The previous type of burner required attention at comparatively frequent intervals in order to maintain a satisfactory high efficiency. The extent to which this maintenance labor will be reduced in the new type will develop from the results of actual practise. It seems reasonable to believe, however, that this reduction should be at least 75 per cent. and probably greater.

The extreme simplicity of the new type, and its inexpensive construction extend its probable usefulness to a degree that can hardly be conjectured. The fixture shown herewith illustrates effects in fixture design heretofore practically impossible in connection with gas. The elimination of the bulky, unsightly and expensive burner housing makes it possible to obtain practically any effect in fixture design required with a unit of 60 candle-power to 1,200 candle-power and upward in size.

It is a simple matter to diffuse the products of combustion so that discoloration of the fixture is avoided and ceiling discoloration greatly reduced, or for a given ceiling discoloration the permissible minimum distance between lamp and ceiling is considerably decreased. This is accomplished by mica baffles, which, on account of the construction adopted may be completely concealed from sight.

It is believed that this new type of burner practically eliminates all substantial objections to gas lighting (with the exception of those inherent in the pilot method of ignition) and will enable the engineer and architect to plan lighting systems practically without reference to the illuminants to be used.

DISCUSSION.

MR. GEO. S. BARROWS: I think that Mr. Pierce has been a little hard in what he said about the manufacturers and their indifference to improvements in burners, and it may be well to consider the cause of this supposed indifference.

At least 20 years ago, elaborate research work was carried on by such men as Lecompt, Denay-Rouze, Bandsept, Kern and many others. This research work extended over a period of years and involved the expenditure of large sums of money. In this country, so far as I know, the manufacturers kept in touch with these foreign developments, making use of such principles of construction as were commercially practical. The different cities in this country were supplied with gas varying in character and pressure, and for years the largest manufacturer of incandescent gas burners, supplied each city with burners adapted especially for the particular requirements of that city. As the business grew, it was found that it was not commercially desirable to have different burners, because of complications in shipping. The burners were then designed to give the best average results, with consequent great increase in commercial efficiency, but with some loss in burning efficiency. The burner finally decided on as being the best to place on the market was not selected until after a long series of tests covering many years had been made, using very carefully designed orifices, raceways and burner heads, and tested not only with burning gas, but with various vapors to show the configuration of the jet, both before and after its mixture with air.

The recent development of the inverted mantle has greatly extended the field for burner design, and the improvements that are now being made are of great value, but it is only just that we give credit to the pioneers in incandescent gas burner construction, who, in their field, did quite as much research work as is being done at the present time.

On the eighth page Mr. Pierce compares the cost of two lamps, illustrating the difference in operating costs in lumen-hours between old and new types. My impression is, and I wish to be corrected if I am wrong, that the burner costing $12 per 200 candle-power is a complete equipment, from the ceiling out-

let, including the fixture, globe, glassware, burners, mantles. I should like to know if the burner costing $2 per 200 candle-power also includes all of the equipment, from the ceiling outlet.

Mr. Norman Macbeth: From such information as I have had of the construction of this burner and its development, I believe that it is something new and different. The investigations carried on have brought out phenomenal results, and with the variety of design made possible from its construction, it should advance the gas interests in the lighting field to a considerable extent.

Gas companies have not always insisted on quality and good material in lighting equipment; nor do many of them do so now. The gas companies have been accustomed to people coming to them for service. The electric companies have had to be different; they have had to go and get customers; and as a result of this they have developed salesmen of stamina and aggressiveness. If the present gas companies would apply some of this spirit and salesmanship there is no doubt that the gas lighting field would be considerably enlarged. There are thousands of buildings in this country that will never have anything but gas lighting in them, and the extent to which this business is developed depends upon the gas company. There is surely something wrong with the present order of things when the consumer in many instances refuses to use gas because the fixtures are plain and cheap while the gas company is continually hammering the lamp and fixture manufacturers to further reduce prices and cheapen the product.

Mr. F. R. Hutchinson: Mr. Pierce and the company he represents are to be congratulated on this and other gas lighting units they have from time to time developed; for we, in the gas industry in America, have not devoted the time and detailed study of increased efficiency and decreased gas consumption apparently given these things abroad.

A comparatively few gas manufacturers work painstakingly in the production of lamps particularly designed to economically and efficiently consume gas with comparatively little trouble and a minimum maintenance cost.

So many cheap, inefficient lamps that give trouble in operation

are sold, that we gas men owe much to those manufacturers, who, through almost endless experiments, accomplish such results as those indicated by Mr. Pierce in his paper describing one type of new lamp.

Gas consumers rarely complain of appliances through which gas is consumed, but rather that the gas is poor.

Wonderful progress has been made in new lighting units, fixtures and glassware, within the last few years, but only a very few of our American gas lamp manufacturers have carefully studied lamp construction in its entirety with a view to producing a lamp of a design differing materially from those originated abroad.

Probably one of the best gas lighted buildings in the United States is the office of the Laclede Gas Light Company in St. Louis. The fixtures and lamps in this building were designed and built along new and original lines. Since these lamps were installed, gas men have been so favorably impressed with the designs, that manufacturers are now building direct, indirect and semi-indirect stock units like, or similar, to those of the latter installation.

This installation is mentioned more to call attention to the fact that had the manufacturer of the burners not assigned a man to design both lamps and fixtures of unusual appearance, as compared with anything in existence at the time, progress in this direction might have been delayed considerably.

The specific gravity and calorific value of the gas have much to do with certain adjustments and parts of the lamp. This point was brought most forcibly to my attention when the company I am connected with converted several thousand gas arc lamps in Cleveland so as to consume natural instead of manufactured gas. I mention this to direct attention to one thing which does not seem to be commented upon in Mr. Pierce's paper, namely, the mouth piece. An expert machanic was employed for probably three weeks experimenting with mouth pieces of slightly varying length and areas before we were satisfied with the results. We are still doubtful but that better results might not now be obtained with a different area and length of mantle than that we are using.

So, in addition to the points covered by Mr. Pierce in his description of lamp parts, if this phase has not been most carefully considered, I would suggest that the mouthpiece area and length be particularly designed for average specific gravity and calorific values of gas in combinations—if there is such a thing—prevailing in different parts of the country.

FACTORY LIGHTING.*

BY OLIVER R. HOGUE AND ALFRED O. DICKER.

Synopsis: The paucity of data on installations of satisfactory general illumination in factories has led to the collection of the data contained in this paper. Recommendations have been omitted, and only a tabular description of the installations is given. The cost of operation and maintenance has been reduced to cost per square foot per month, as the authors believe that this is an appealing argument to the factory owner to convince him that for improving operating and general sanitary conditions light is an important consideration, and is not an expensive operating charge.

In this paper we have sought to gather and present in convenient form data which will show the present trend of factory lighting practise, particularly in Chicago. We do not, however, recommend or specify how much light should be supplied for this class of business; we merely submit data on intallations we have made and which have proved satisfactory to the factory owner as to design, price and appearance. The installations referred to were made by the Commonwealth Edison Company, Chicago, under a special factory lighting proposition.

Following is the form of contract which the factory customers were required to sign. Three charges are mentioned in this contract: (1) rental, (2) maintenance, (3) electricity.

The rental charge continues throughout the two-year period of the contract and includes the cost of the installation complete with wiring, and fixtures. At the end of the two years the installation becomes the property of the consumer.

The maintenance charge continues throughout the contract period with the exception of June, July and August of each year. The company furnishes a ten-day cleaning service, renews all burned-out lamps and keeps the installation in good working condition.

The electricity charge is based on the company's regular rates for lighting service, 10, 5 and 3 cents per kw.-hr.

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

RIDER No. 8. TUNGSTEN FACTORY LIGHTS—METER BASIS.

(Applicable to Rates "A" and "C," except Limited-Hour Service and

Alternating Current Untransformed.)

Rider to be attached to, and hereby made a part of, that certain contract or application

hereinafter referred to as the "contract"), dated . . . . , 191 . . , for electric service to be furnished by **Commonwealth Edison Company** (herein and in said contract called the Company) to the undersigned **Customer.**

Service requested. In consideration of the customer's agreeing to pay the rental and maintenance charges hereinafter mentioned, the Company agrees, upon the conditions herein stated, (1) to furnish, install, connect and maintain upon the Customer's premises (being a factory or loft) at No. . . . .

. . . . , Chicago, Illinois, ... (not less than five) Tungsten factory lights of the Company's standard type and finish, each such light to consist of a single mazda lamp of 100, 150 or 250-watt capacity, as the Customer may designate, and a factory lighting fixture, to be suspended from the ceiling; (2) to furnish, for and during the life of said contract (at the rates mentioned therein and in accordance with the terms thereof), electricity for the lighting of said lamps, beginning about . . . . 191 . . ; and (3) to equip said premises with such wiring as may be necessary for lighting said lamps, such wiring to be what is commonly known as "exposed conduit work."

Term of contract. In case said contract be under the Company's rate for "General Service" (Rate "A"), the contract shall continue for a fixed term of . . . .

. . . . (not less than 2) years from the date when service begins hereunder, and after said fixed term until terminated upon notice in the manner provided in said contract.

Rental Charge. The Customer agrees to pay to the Company for and during the life hereof, subject to the provisions hereinafter stated, a rental charge for the use of said wiring and other electrical equipment of 25 cents per month per factory light installed. When and if said lights shall have been supplied with the Company's electricity for a period of 24 consecutive months, provided the Customer shall then have fully complied with all his obligations hereunder, the Customer's obligation hereunder to pay such rental charge shall thereafter cease, and said wiring and equipment, not including lamps, shall thereupon, but not until then, become the property of the Customer.

Maintenance charge. In addition to said rental charge, the Customer agrees to pay to the Company for and during the life hereof, subject to the provisions hereinafter stated, a maintenance charge for the Company's care and maintenance of said equipment and lamps (including the furnishing and installing of renewals of said lamps) of 25 cents per month per factory light installed, except that no maintenance charge shall be payable for the calendar months of June, July and August in each year. When and if said lights shall have been supplied with the Company's electricity for a period of 24 consecutive months the Customer may, if he so elects, and upon giving the Company 10 days' written notice of such election, thereafter maintain said equipment at his own expense, and in such case his obligation hereunder to pay such maintenance charge shall thereupon cease; but unless and until the Company shall receive such 10 days' notice, it will continue to maintain said equipment and lamps and the Customer shall continue to pay such maintenance charge in accordance with the provisions hereof.

(OVER)

(*Reverse Side of Rider.*)

Electricity charge. In addition to said rental and maintenance charges, the Customer agrees to pay the Company for all electricity consumed by said lamps at the rates specified in the contract to which this rider is to be attached.

Additional charge under Rate "C". In case said contract is for service under the Company's Rate "C", it is further agreed, irrespective of anything in said contract contained, that the Customer shall pay to the Company for each month hereafter (in addition to the demand and energy charges specified in said contract, and in addition to said rental and maintenance charges), a sum equal to ½ cent for each kilowatt-hour of electricity consumed in such month by the lamps installed hereunder.

Terms and Conditions. During such time as the Company is required to maintain the mazda lamps furnished and installed hereunder, the Company will, at the request of the Customer, when said lamps are worn out, furnish and install renewals thereof without extra charge. All renewals of lamps furnished hereunder shall be of the same kind and wattage as the lamps originally supplied. The Customer shall in no case remove from the fixtures, loosen, partially unscrew or in any way tamper with any of the madza lamps or renewals thereof. The Customer shall pay the Company, at the Company's regular prices, for all lamps and renewals thereof furnished by the Company and removed from the fixtures by the Customer, also for all lamps or renewals thereof broken or unaccounted for, and also for all unaccounted for, broken or damaged shades furnished by the Compaay for said lamps. Should the Customer desire to change the location of any of said factory lights after its first installation, such change will be made by the Company at the Customer's expense. All fees charged by the City for the inspection of the electrical equipment in said premises shall be paid by the Customer.

In case the Company shall discontinue service under said contract for failure by the Customer to comply with or perform any of the conditions or obligations thereof or of this rider, in addition to all other amounts then due there shall immediately become due and payable to the Company, as liquidated damages, not as a penalty, a further sum equal to such proportion of the cost to the Company of furnishing and installing in and about the Customer's premises the electrical equipment required hereunder, as the then unexpired portion of said fixed term bears to the entire fixed term.

Nothing in this rider contained shall in any way affect the terms and provisions of said contract except to the extent that such terms and provisions are in conflict with, and therefore superseded by, the foregoing provisions of this rider.

This Rider shall not be binding upon the Company until accepted in writing by the Company's General Contract Agent.

Accepted: . . . . , 191 . . . .

CUSTOMER

COMMONWEALTH EDISON COMPANY By . . . .

By . . . .

General Contract Agent. (Official Capacity)

The contract covers only general lighting inasmuch as the customer is required to pay extra for any drop cords which may be installed. Several shops have provided drop cord outlets near the larger machines. Drop cords are not allowed to be used while the machine is in operation. This requirement eliminates danger from short circuits due to the cord coming in contact with moving parts of a machine.

The necessity of a special proposition was made very evident

after a thorough field canvass. It was found that the average manager wanted better lighting but was unwilling to pay the high first cost of installation. With this objection removed, as indicated in the special contract form, and with three salesmen covering the two hundred square miles of Chicago, it is possible to install about 500 units per month.

EQUIPMENT.

Many different types of reflectors were tried before the one

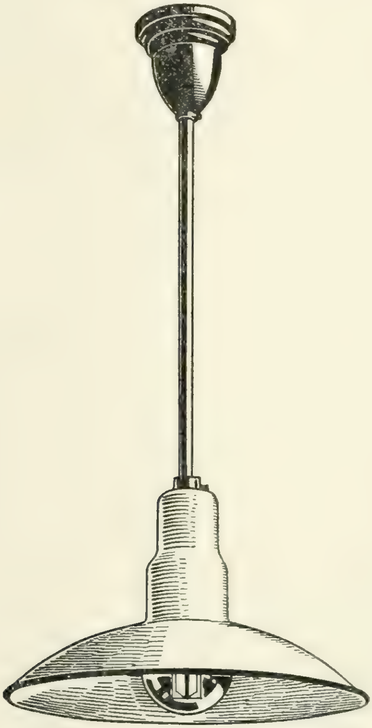


Fig. 1.

shown in Fig. I was selected. The reflector is of the shallow-bowl type, steel, white-enameled and available in three sizes for 100, 150 or 250-watt lamps. It was designed to satisfy the following somewhat difficult requirements of this class of lighting. First, three sizes were considered as the maximum number

which could be supplied under the given rental proposition. Second, the reflectors must have photometric characteristics which will under the average factory conditions furnish good general illumination. Third, the reflector must be one on which the maintenance will be low, and at the same time be rugged enough to withstand the wear and tear of factory use. A photometric curve of the 150-watt reflector is shown in Fig. 2. The other reflectors show approximately the same characteristics.

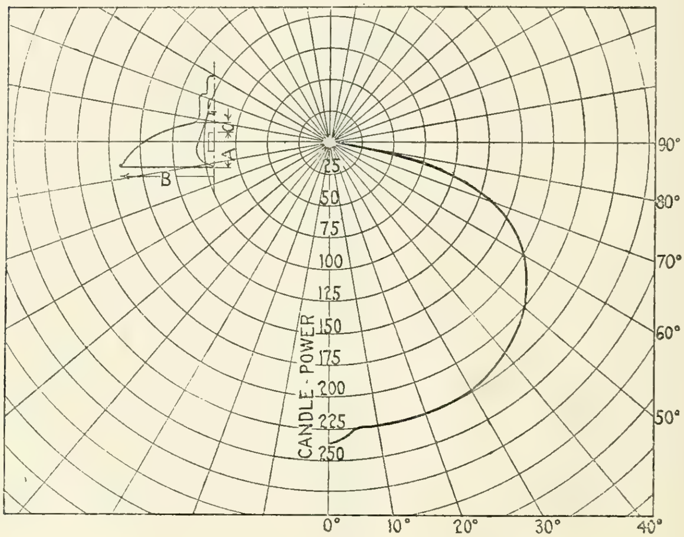


Fig. 2.

All wiring is run in exposed conduit. There have been practically no complaints from the customers. In a few cases the length of a fixture stem or the location of the unit has been changed.

DATA.

For convenience the data have been arranged in four tables: I. Installation Data; II. Cost of Installation; III. Maintenance Data; IV. Total Cost to Consumer.

Installation Data.—In this table is given a general idea of the lighting installations and some of the important factors which influenced the amount of light furnished.

TABLE I. —INSTALLATION DATA.

Installation	Class of service	Kind of work done	Localized lighting	Overhead belting	Units installed 100 W	150 W	250 W	Total watts	Area sq. ft.	Watts per sq. ft.	Ceiling height	Hanging height of fixture	Method of control
I	II	III	IV	V	VI			VII	VIII	IX	X	XI	XII
1	Tailor shop. . . .	Bench and machine	No	No	13	17	. . .	3,850	6,000	0.642	12 ft. 0 in.	7 ft. 0 in.	Individual switch
2	Tailor shop (light goods)	Bench and machine	No	No	22	3	. . .	2,650	9,000	0.295	12 " 0 "	7 " 0 "	Individual switch
3	Tailor shop. . . .	Bench and machine	No	No	. . .	20	. . .	3,000	14,000	0.214	12 " 6 "	10 " 0 "	Individual switch
4	Tailor shop. . . .	Bench and machine	No	No	. .	26	. . .	3,900	9,200	0.424	12 " 3 "	10 " 0 "	Individual switch
5	Dress making (hand)	Bench	No	No	. . .	53	. .	7,950	7,600	1.050	14 " 0 "	11 " 5 "	Individual switch
6	Waist mfgrs. . . .	Bench and machine	No	No	3	20	. . .	3,300	10,000	0.330	14 " 0 "	9 " 6 "	Individual switch
7	Men's clothes (wholesale) . .	Bench	No	No	2	23	. . .	3,650	9,000	0.405	14 " 0 "	12 " 0 "	Individual switch
8	Mfg. underwear	Bench and machine	No	No	. . .	21	. . .	3,150	7,500	0.420	12 " 0 "	10 " 0 "	Individual switch
9	Mfg. dress trimmings	Bench and machine	No	Yes	91	39	. . .	14,950	36,000	0.415	12 " 0 "	8 " 9 "	Individual switch
10	Laundry	Machine	No	Yes	. .	8	3	1,950	1,800	1.084	18 " 0 "	12 " 0 "	Individual switch
11	Laundry	Machine	No	Yes	. . .	. . .	34	8,500	14,000	0.607	14 " 0 "	12 " 0 "	Individual switch
12	Mfg. leather goods.	Bench and machine	No	No	. . .	17	. .	2,550	6,000	0.425	12 " 0 "	9 " 0 "	Central control
13	Paper box mfgr. .	Bench	No	No	. . .	16	. . .	2,400	7,200	0.333	12 " 0 "	10 " 0 "	Individual switch
14	Mfg. metal stamps.	Bench and machine	No	Yes	16	8	. . .	2,800	6,000	0.466	14 " 0 "	9 " 0 "	Individual switch
15	Mfg. name plates	Bench and machine	Yes	Yes	6	16	3	3,750	10,000	0.375	12 " 0 "	10 " 5 "	Individual switch
16	Machine shop . .	Machine	Yes	Yes	. .	5	16	4,750	15,000	0.317	11 " 0 "	10 " 0 "	Individual switch
17	Mfg. magnetos. .	Machine and bench	Yes	Yes	. . .	15	. . .	2,250	6,000	0.375	16 " 0 "	12 " 0 "	Central control
18	Mfg. machine tools	Machine and bench	Yes	Yes	5	21	. . .	3,650	10,800	0.338	13 " 0 "	9 " 0 "	Individual switch
19	Mfg. metal wheels.	Machine and bench	No	Yes	4	13	. . .	2,350	9,100	0.258	14 " 0 "	11 " 0 "	Individual switch
20	Mfg. steel ovens .	Machine	No	No	1	20	5	4,350	8,500	0.512	14 " 0 "	10 " 0 "	Individual switch
21	Mfg. envelopes. .	Bench and machine	No	Yes	4	32	1	5,450	9,600	0.568	12 " 0 "	9 " 0 "	Individual switch
22	Mfg. washing compounds. . .	Bench and floor . .	No	No	10	. . .	. . .	1,000	4,800	0.208	12 " 0 "	8 " 9 "	Individual switch
23	Brass foundry . .	Floor, machine and bench	No	Yes	58	22	2	9,600	29,000	0.331	27 " 0 "	11 " 0 "	Individual switch
24	Mfg. wagons and repairs.	Machine and bench	No	Yes	. . .	15	1	2,500	6,000	0.425	14 " 0 "	11 " 0 "	Individual switch
25	Mfg. wagons and repairs.	Machine and bench	No	Yes	10	23	. . .	4,450	10,000	0.444	18 " 0 "	11 " 0 "	Central control

TABLE II.—COST OF INSTALLATION.

Instal-lation	Location in building, floor	Building previously connected	Building construction	No. of floors covered by installation	No. of lamps installed			Method of switching	Total cost	Cost per unit
					100 W	150 W	250 W			
I	II	III	IV	V	VI			VII	VIII	IX
1	4	Yes	Brick mill	1	13	17	..	Individual switch	$211.42	$7.05
2	2	Yes	Brick mill	1	22	3	..	Individual switch	68.90	2.76
3	4	Yes	Brick mill	1	..	20	..	Individual switch	188.61	9.43
4	6	Yes	Brick steel	1	..	26	..	Individual switch	234.62	9.03
5	4	Yes	Brick mill	1	..	53	..	Individual switch	423.02	7.98
6	6	Yes	Brick mill	1	3	20	..	Individual switch	205.60	8.94
7	2	Yes	Concrete	1	2	23	..	Individual switch	162.94	6.52
8	4	Yes	Brick mill	1	..	21	..	Individual switch	124.17	5.91
9	2, 3 and 4	No	Brick mill	3	91	39	..	Individual switch	810.27	6.23
10	1	Yes	Brick mill	1	..	8	3	Individual switch	82.35	7.49
11	1 and 2	No	Brick mill	2	..	..	34	Central control	319.52	9.40
12	2	Yes	Brick mill	1	..	17	..	Individual switch	159.64	9.39
13	3	No	Brick mill	1	..	16	..	Individual switch	148.80	9.30
14	1 and 2	No	Brick mill	2	16	8	..	Individual switch	172.99	7.21
15	1 and 2	Yes	Concrete	2	6	16	3	Individual switch	179.09	6.85
16	1 and 2	Yes	Brick steel	2	..	5	16	Individual switch	207.51	9.88
17	1	No	Concrete and steel	1	..	15	..	Central control	116.11	7.74
18	4	Yes	Brick mill	1	5	21	..	Individual switch	168.78	6.49
19	1	Yes	Concrete	1	4	13	..	Individual switch	56.79	3.34
20	1	No	Brick mill	1	1	20	5	Individual switch	228.06	8.77
21	5	No	Brick mill	1	4	32	1	Individual switch	259.43	7.01
22	1 and 2	No	Brick mill	2	10	..	..	Individual switch	96.20	9.62
23	4, 5 and 6	Yes	Brick mill	3	58	22	2	Individual switch	396.89	4.84
24	1	Yes	Brick mill	1	..	15	1	Individual switch	144.13	9.01
25	2	No	Brick mill	1	10	23	..	Central control	248.01	7.52

TABLE III.—MAINTENANCE DATA.

Installation	Units installed			Lamps renewed			Life of lamps	Hour use per day of connected load
	100 W	150 W	250 W	100 W	150 W	250 W		
I	II			III			IV	V
1	13	17	..	1	2	..	2,916	1.080
2	22	3	..	8	2	..	494	0.706
3	..	20	..	..	7	..	986	1.250
4	..	26	..	..	9	..	1,810	2.000
5	..	53	..	..	10	..	3,360	2.120
6	3	20	..	2	6	.	1,930	2.300
7	2	23	..	1	5	..	2,605	1.780
8	..	20	..	..	2	..	1,056	2.900
9	91	39	..	20	9	..	457	0.348
10	..	8	3	..	9	5	1,325	5.640
11	..	..	34	..	..	11	996	1.110
12	..	17	..	..	3	..	1,821	0.960
13	..	16	..	..	5	..	1,914	2.060
14	16	8	..	1	1	..	3,240	0.540
15	6	16	3	2	3	1	4,270	3.280
16	..	5	16	..	3	10	1,720	3.620
17	..	15	..	..	3	..	2,532	1.820
18	5	21	..	2	9	..	890	1.220
19	4	13	..	1	3	..	1,580	1.210
20	1	20	5	2	10	2	1,287	2.420
21	4	32	1	3	9	2	2,320	1.610
22	10	..	..	3	..	..	1,301	1.990
23	58	22	2	24	11	8	2,160	3.780
24	..	15	1	..	2	1	1,602	0.820
25	10	23	..	11	21	..	700	2.280

In the sub-heading 'Kind of Work Done,' three descriptive terms, *i. e.*, bench work, machine work, and floor work are used. These are rather indefinite, because of the various nature of work which may be done under a given installation. However, this heading together with the information under the heading 'Class of Service' gives a fairly clear idea of the requirements of each lighting system.

The column 'Watts per square Foot' is interesting. It shows a range from a maximum of 1.08 to a minimum of 0.208 watt per square foot. There are two installations above one watt per square foot, *viz.*, installations Nos. 5 and 10. No. 10 is a hand laundry having large glass windows so that people passing the place may see the operators at work. With this advertising feature in mind, the owner provided more light than was recommended by the engineering department of the lighting company.

TABLE IV.—COST TO CONSUMER PER MONTH.

Installation	Units installed			Rental charge per month	Maintenance charge per month	Electricity charge per month	Total charge per month	Area covered	Lighting load factor	Ratio maximum to connected load	Total cost per square foot per month (cents)
	100 W	150 W	250 W								
I	II			III	IV	V	VI	VII	VIII	IX	X
1	13	17	..	$ 7.50	$ 5.63	$15.29	$28.42	6,000	0.090	0.501	0.474
2	22	3	..	6.25	4.68	5.25	26.18	9,000	0.048	0.615	0.180
3	..	20	..	5.00	3.75	28.15	36.90	14,000	0.071	0.735	0.263
4	..	26	..	6.50	4.87	15.07	26.44	9,200	0.114	0.740	0.288
5	..	53	..	13.25	9.95	27.81	51.01	7,600	0.109	0.810	0.540
6	3	20	..	5.75	4.31	15.84	25.90	10,000	0.097	0.990	0.259
7	2	23	..	6.25	4.68	12.33	23.26	9,000	0.111	0.670	0.259
8	..	20	..	5.25	3.75	16.73	25.73	7,500	0.121	1.000	0.343
9	91	39	..	32.50	24.37	17.90	74.77	36,000	0.029	0.497	0.208
10	..	8	3	5.25	2.06	16.81	24.12	1,800	0.345	0.687	1.440
11	..	..	34	8.50	6.37	17.10	31.97	14,000	0.139	0.334	0.228
12	..	17	..	4.25	3.19	17.14	14.58	6,000	0.044	0.915	0.243
13	..	16	..	4.00	3.00	14.97	21.97	7,200	0.164	0.530	0.305
14	16	8	..	6.00	4.50	4.60	15.10	3,000	0.037	0.605	0.503
15	6	16	3	6.25	4.68	19.69	30.62	5,000	0.117	0.866	0.593
16	..	5	16	5.25	3.94	23.98	33.17	15,000	0.111	0.995	0.221
17	..	15	..	3.75	2.81	12.62	19.18	6,000	0.134	0.585	0.320
18	5	21	..	6.50	4.87	14.57	25.94	10,800	0.105	0.484	0.239
19	4	13	..	4.25	3.19	6.73	14.17	9,100	0.144	0.349	0.156
20	1	20	5	6.50	4.87	18.63	30.00	8,500	0.163	0.618	0.353
21	4	32	1	9.50	6.75	26.19	42.44	9,600	0.110	0.830	0.442
22	10	..	..	2.50	1.88	4.50	8.88	4,800	0.083	1.000	0.185
23	58	22	2	20.50	15.35	50.80	86.65	29,000	0.189	0.835	0.298
24	..	15	1	4.00	2.81	11.05	17.86	6,000	0.081	0.426	0.298
25	10	23	..	9.25	6.18	24.79	40.22	10,000	0.152	0.626	0.402

Illumination tests of these installations have not been made, but with the data given the illumination intensity in each case may be readily determined.

In connection with the data given, we wish to state that the most extensive or most complete installations have not been selected; rather we have tried to give data from average installations.

It may be digressing a little from the subject to mention one point which is important in the installations, *viz.*, the lighting of the ceiling. In lighting a large factory space with opaque reflectors care must be exercised to provide in some way sufficient light for the ceiling if overhead belting is used. Often a repairman is exposed to danger in repairing belts in such shops. This is particularly true in factories where it is necessary to install the fixtures on rather long stems. This difficulty has been provided for in the design of the reflector. By loosening a screw in the collar, the reflector may be raised on the stem allowing the bare lamp to be exposed and thus furnishing sufficient light for the repairman to repair belts with safety.

Cost of Installation.—Under this heading are given factors which influence the cost of the installation. It must be remembered that the company, in addition to wiring and furnishing the fixtures, carries this account for two years. All items of expense are included in the total cost.

To many the cost per outlet may, at first thought, seem high, but when the type of workmanship and the strict city rules governing this class of work are considered the reason for this unit cost is clear. Another important factor is the fact that many of these installations are on the fourth and fifth floors of buildings which means risers must be run from the basement to take care of this additional load.

The control of these lamps may, at the consumer's option, be either of two systems, *i. e.*, individual control of the units by a pull switch which is installed in an iron box 18 in. (46 cm.) from the fixture, or by a central switch located in a cabinet in a convenient place. The most satisfactory method has proved to be the method of individual control. In this manner the employees may be required to turn off the lamps except when

needed. In one large factory where the piece work system is employed the operators are subject to demerits if lamps near them are found burning when not necessary. This is an effective way of reducing the cost of operating the lighting system. The cost of installation per unit ranges from a maximum of $9.88 to a minimum of $2.76, or an average of $7.00 per unit.

Maintenance Data.—As stated in the contract form the company maintains the lighting system during the period of the contract, which is two years. During this period the installation is cleaned every ten days. At the time of cleaning the lamps are renewed if necessary and any minor repair work required is done. We believe that cleaning at this stated interval is absolutely necessary to the success of the installation. In a certain factory a deterioration in light during a period of 7 days was shown to be 32 per cent. This case may be exceptional; but probably the lighting system would have been condemned by the manager had the company not furnished a maintenance service. These installations are maintained close to their initial efficiencies which is not the case in many factories with which we are familiar.

In the table on maintenance data we give only the number of lamps renewed and the life of each one under actual operating conditions. The cost of replacing reflectors and the minor repair work is insignificant.

The column headed 'Lamps Renewed' is reduced to lamps renewed per 300-day year. This item shows a range from a maximum of 4,270 to a minimum of 457, or an average of 1811 lamp hours.

Cost to Consumer Per Month.—Always the most important consideration to the manager is the matter of cost. "Is it worth the expense?" is a question to which he must have a convincing answer. Under this heading we have attempted to show the actual cost to the consumer. While this data is based, as we have stated, on a special proposition, we know by comparison that the total cost per square foot per month is very close to the figures of similar installations not included in this proposition.

In this table we have included the 'Lighting Load Factor' and

'Ratio of Maximum to Connected Load.' By load factor we mean the ratio of the hours use of the maximum demand per day to twenty-four hours of the day.

The 'Ratio Maximum Demand to Connected Load' is determined by readings taken from maximum demand meters which are installed for each installation.

The 'Total Cost per Square Foot per Month' varies through a rather wide range of from a maximum of 1.440 cents to a minimum of 0.156 cents. The maximum, however, is installation No. 10, which, as stated before, is rather an exceptional case.

In conclusion the authors desire to state that since entering the factory lighting business they have been surprised by the large number of opportunities to improve lighting conditions in this great field. We cannot help but wonder at the apparent disregard of lighting in so many factories. It is astonishing at this age to hear so many owners and managers state that they have never given lighting much thought; and yet they are ever striving to reduce the cost of manufacturing their product.

It would seem to be one of the functions of this society to furnish such publicity to the manufacturing world as would enable them to see that good lighting offers opportunities to further improve operating efficiency. This is apparently a problem for our society rather than individual engineers or companies; for no matter how conscientious the individual or company which has something to sell, may be, the man who pays the bills often feels that the advise is good salesmanship rather than good sound engineering advice.

The booklet "Industrial Lighting," published by the commercial section of the National Electric Light Association in 1912, has been a great benefit in our work. Cannot this Society publish a pamphlet on factory lighting even more comprehensive than this, and would we not all be benefitted by it? It would seem that a great duty of this Society would be to educate the users of light to better practise in lighting.

DISCUSSION.

Mr. Ward Harrison: Several points brought out by the speaker illustrate the difference between operating a lighting system in one's own plant and working out a practical plan to improve industrial lighting generally. One of those is the question of glass or steel reflectors. We find that it is not difficult nowadays to show a man the desirability of an installation of good steel reflectors; whereas to convince the same man that he should put in an installation of glass reflectors requires much argument. The rate of breakage may be low, but most plant managers think it is going to be high, and it is difficult to convince them to the contrary. It has been found that, as a rule, one can expect to get a higher efficiency with glass than with any other reflector of the same shape. In our factories we are using diffusing glass reflectors quite extensively, because we know that the breakage will be small and we have the advantage of better ceiling illumination and consequently better diffusion of light. We are using a bowl shape rather than the dome because we get nearly as good efficiency, and a much greater degree of eye protection.

I believe that the standardization, spoken of by the authors, is an excellent plan. If each lighting installation in an industrial plant could be designed by an illuminating engineer, it is possible that the adoption of a great many different systems would be justifiable. As a matter of fact this can seldom be the case. Whereas, the aim in commercial lighting is to be individual, in industrial lighting efficiency and economy are sought; therefore the tendency to standardization and to similarity are dominant. Specifications should be made general enough to apply to most of the cases to be met with in a given industry. Then even though the application may not be as perfect in every case as if the specifications were prepared especially, it may so nearly approach that condition that the extra expense and complication of a special layout would not be justified. After a number of installations have been made according to such specifications, the uniformity of the example they will set to a man intending to make an installation will cause him to go and do likewise.

The effect of a few good examples is illustrated by the change

which has taken place in the demand for reflectors. Formerly most industrial plants purchasing reflectors on their own initiative selected a flat shade of cheapest variety. From a recent conversation with a number of reflector manufacturers, however, I learned that during the past two years the relative increase in the call for reflectors of better grade as to design, efficiency and durability has been enormous. I believe that this change may be attributed in very large measure to the influence of installations planned by members of this Society.

In an effort toward the standardization of spacing rules, we have made many illumination tests covering the uniformity of illumination. As a rule, we find that the spacing of units is controlled by the ceiling height. In a shop of large area where general illumination is required, it is usually advisable to hang the lamps as high as possible and to make the spacing approximately 60 per cent. greater than the distance between the unit and the working plane. The wattage of the lamps chosen will then depend only upon the intensity desired. The area covered by each lamp is fixed; hence the product of that area in square feet by the foot-candles desired gives the lumens that must reach the working plane. This divided by the utilization factor of the system, usually from 45 to 65 per cent., gives the total lumens required from each lamp. The size of the lamp can then be determined from published data. Where diffusing reflectors of almost any common type are used, the above method results in uniform illumination. It has been followed extensively with satisfactory results by engineers and plant superintendents who design their own installations.

MR. G. H. STICKNEY: Outside of the data, it seems to me that this paper is important as an example to central stations, on account of the fact that it indicates that one of the most progressive central station organizations in the country thinks it desirable to organize for the solicitation of industrial lighting business. I would like to ask Mr. Dicker if, after the experience of the last year or two, he is still convinced that the industrial lighting business is profitable to central stations. If this is so, it would seem to me that some central stations in this country are missing a good opportunity.

The practise described by the authors seems to show a very considerable degree of standardization. The industrial lighting field yields more readily to such practise than almost any other, and the sooner we can secure standardization of lighting practise for the various industrial processes, so much quicker will good illuminating engineering practise be applied in this field.

MR. H. CALVERT: There are several questions of policy in this paper which are open to discussion, but the conclusions reached depend upon the judgment of those having the final authority. Is it necessary, or even advisable, for a central station to assume the initial investment of wiring a building for electricity, or piping a building for gas? Should not all classes of consumers be treated alike? Is it advisable to assume the initial investment for a factory, and yet turn to the owner of a small store adjacent and tell him, we are very sorry, but we cannot do anything for you.

In regard to the size of lamps used, the 100, 150 and 250-watt lamps are all high candle-power illuminants, and if the proposition is limited to these sizes, then all efforts must be confined to large rooms.

With respect to maintenance, inspecting and cleaning every ten days, while undoubtedly necessary in some particular cases where the installation is subjected to a larger amount of dirt or smoke, seems entirely too frequent. Certainly after the company's inspection is over the owner will not give the installation the same amount of attention.

It will be interesting to know in this connection whether the total cost to the consumer includes interest on the money which the company has to invest, and also the cost of its cleaning and inspection.

MR. ALFRED O. DICKER (In reply): In regard to Mr. Stickney's question, "Is industrial lighting alone good business?" My instructions from the company have always been, "Any business is good business." This may apply better to conditions as they existed a month or two ago than they do at the present time. There is little question about the value of this business to the company. In the first place, you will note that many of these buildings were previously connected, but the system was replaced.

improved, or other rooms were added. This proposition has reached into a new field, which has been almost out of the range of the central stations because of the expense that would be incurred in getting the risers up to the fourth and fifth floors of a building. We have been able to do this.

Mr. Calvert asked if it was fair to the company for the central station to carry the investment cost. We believe it is. We have introduced more electric light into Chicago through the rental proposition than by any other method, I believe. We have twenty or more different rental propositions, covering almost every class of service. We have four or five store propositions, we have street lighting, street posts and exterior brackets, and almost anything that a customer wants. This is certainly considered by the company as good business.

Only 100, 150 and 250-watt lamps are used because this is primarily a system of general illumination, and lamps smaller than that would hardly be considered, although we supply anything from 60 watts up free.

Mr. Calvert also asked what the total cost to the consumer includes. We have tried to make it include everything. It includes interest on the installation and our cost of everything furnished in that installation.

One gentleman has asked if the lamps are evenly spaced. We have tried in many cases, at least, to do this, although it is readily seen that one could not adhere to any such regulation. Practically all of this lighting is installed, as I stated, by men traveling out of our illumination department, and that department has supervision over the work they do.

What I called a contract here is a rider appended to a regular application for lighting service.

There is one thing I might call to your attention, and that is that most of this class of business is in the smaller factories. The large factory usually prefers to buy an installation outright.

LIGHT FILTERS FOR USE IN PHOTOMETRY.*

BY C. E. KENNETH MEES.

Synopsis: Eight new photometric filters in two sets of four each have been developed for reducing color differences in ordinary photometry and are now available for photometric laboratories. One set (blue) reduces lower efficiency light to higher; the other (yellow) reduces higher to lower efficiency in color.

In practical photometry it is frequently necessary to compare light sources of slightly different colors, especially electric lamps burning at different efficiencies, and the accuracy of balance which can be obtained is necessarily much diminished in such cases. The error can be lessened if a color filter is used which equalizes the color in the two fields of the photometer by absorption, the transmission of this filter being determined by a number of observers and a factor settled once for all from those determinations. Photometrists have been accustomed to use blue glasses placed in front of the lamp of lower efficiency, but it is very difficult to find glasses which enable a really satisfactory color match to be made, so that the glasses in general use only represent a partial solution of the problem.

With the introduction of the new high efficiency tungsten lamps the difficulty in working with lamps at different efficiencies has grown greater, and Mr. Mackay of the research laboratory of the General Electric Company invited the Eastman Kodak Company Research Laboratory to prepare a set of filters for photometric use including both yellowish filters for reducing high efficiency lamps to the color corresponding to that of lamps of lower efficiencies, and bluish filters for the inverse process. After a considerable number of trials a series of eight filters, four of each color, have been prepared giving very perfect color matches, there being practically no pink or greenish residual color. These filters are as follows:

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

No. 78 (bluish) reducing color of 1.25 watts per candle tungsten to sensation daylight.

No. 78A reducing 1.25 watts per candle tungsten to 0.36 watt per candle tungsten.

No. 78B reducing 1.25 watts per candle tungsten to 0.60 watt per candle tungsten.

No. 78C reducing 1.25 watts per candle tungsten to 0.88 watt per candle tungsten.

No. 86 (yellowish) reducing daylight to 1.25 watts per candle tungsten.

No. 86A reducing 0.35 watt per candle tungsten to 1.25 watts per candle tungsten.

No. 86B reducing 0.60 watt per candle tungsten to 1.25 watts per candle tungsten.

No. 86C reducing 0.95 watt per candle tungsten to 1.25 watts per candle tungsten.

These filters can also be applied to the reduction of carbon lamps to match tungsten.[1]

No. 78A reduces carbon at 3 watts per candle to 1.25 watts per candle tungsten.

No. 86A reverses this, reducing the tungsten to match the carbon.

Combinations of the other filters can be used if the carbon is burning at other efficiencies. A 116-volt carbon lamp burning at 102 volts matches 1.25 watts per candle tungsten when the tungsten is screened with filters 86A and 86C used together. Similarly filter No. 78B reduces carbon run at 127 volts to 1.25 watts per candle.

Experiments were made to see whether lamps could be set up to a given efficiency simply by color match. A particular lamp, for instance burnt at 0.60 watt per candle at 153 volts—a 1.25 watts per candle tungsten was screened with filter No. 78B and the resistance in the high efficiency lamp circuit was varied until a color match was obtained, the voltage then being read. It was found that in this way the lamps could be set by color match to one volt. In the case of the blue filters No. 78 series different observers set lamps by color match to the same voltage within the error of observation, but with the yellow filters No. 86 series there were slight systematic differences amounting to two or three volts between different observers. This was found to be due to the fact that although the No. 86 filters give a good sensa-

[1] The tungsten lamps referred to in this paper were of the vacuum type.

tion match they do not give a complete spectral match, whereas the blue filters give an almost perfect spectral match. It is consequently better to use the blue filters for setting up lamps to efficiencies by color, and they should be very valuable for this purpose as they avoid the necessity of using the integrating sphere to get the spherical candle-power. An attempt was made

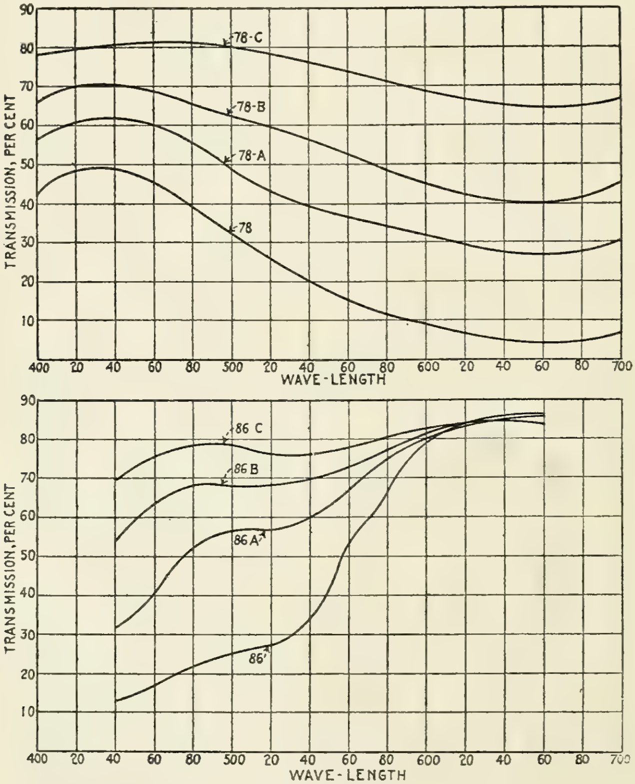


Fig. 1.—Color transmission of light filters.

to use the yellow filters for this purpose by placing in front of the eye a supplementary color filter which cut out all the green of the spectrum, transmitting only the red and blue, but although this removed the disagreement between different observers it diminished sensibility somewhat. The colorimetric analyses and total transmission of white light of the new filters are as follows:

No.	Dominant hue	Impurity Per cent.	Total transmission Per cent.
86	5887	25.7 white	60
86A	5817	52.2	75
86B	5798	62.5	84
86C	5783	75.5	85
78	4788	34	18
78A	4784	82	39
78B	4800	91	54
78C	4810	96	74

The spectrophotometric absorption curves of these new filters are given in the figure.

The writer's thanks are due to Dr. P. G. Nutting and Mr. L. A. Jones, who made the measurements on these filters.

DISCUSSION.

MR. F. E. CADY: I would like to add merely one point; it bears directly on this paper. Dr. Mees has given on the fourth page total transmission in per cents. The transmissions may be and probably are accurate, and might be perfectly satisfactory for the purpose for which the filters were originally made, namely, for use by Mr. Mackay; but in photometric work, accurate photometric work, it would be highly desirable that more information be given as to just how these values of transmission were obtained and to what accuracy they are given; that is, whether the second figure is the last significant figure.

MR. L. J. LEWINSON: I would like to ask Dr. Mees to state what he considers the magnitude of the error of observation, referred to near the bottom of second page. One volt in 153, or approximately 0.65 per cent., corresponds to very nearly 10 per cent. in life. I bring up this point because of the reference to slight systematic differences amounting to 2 or 3 volts, given on the same page. Such differences might mean 20 to 30 per cent. in life.

At the Electrical Testing Laboratories we have made preliminary experiments in setting up lamps at w. p. c. by means of color screens. Using 100-candle-power, 7.5-ampere, series lamps, we found average variations of about 3/4 of 1 per cent. in amperes, which would correspond to about 18 to 20 per cent. life. This would be very unsatisfactory for life test work. It

should be stated that the operators who obtained these measurements were skilled photometrists, but were not experienced in color matching.

MR. W. F. LITTLE: I wish to ask Mr. Mackay if he can give the transmission of the blue screen when using it to correct the color of a 4-w. p. c. carbon to that of a 1¼-w. p. c. tungsten, and when using it to correct the 1¼-w. p. c. tungsten to a 0.6-w. p. c. gas-filled lamp. Also, is there a change, and to what extent when reversing the operation with the yellow screen?

MR. G. M. J. MACKAY: Of course, when lamps of different color, are used, the screen will have a different coefficient of transmission This makes it more advantageous, from the pyrometer standpoint, to use the blue glass with the standard lamp, which is maintained, say, 1½ watts per candle-power, and to vary the apparent temperature by using screens or filters of different intensities of color, and then to calibrate them once for all in terms of transmission of the light of this standard which is maintained at the same voltage.

DR. C. H. SHARP: The well-known fact which has been brought to our attention by a previous speaker, namely, that the candle-power of lights of different color does not completely describe them is of far more immediate interest to the physicist than to the engineer. For engineering purposes the one most important datum regarding an illuminant is its candle-power or total luminous flux. It is because the color screens which Dr. Mees has given us enable us to measure this quantity with greater facility and with greater accuracy that we have reason for congratulation. It has become increasingly evident that the most promising way around the difficulties of heterochromatic photometry at the present time is to make the leap from one color to another once for all by determining through the medium of a number of observers at different laboratories the absorption coefficients of standard light filters used under definite conditions. Engineering work, then, done with the medium of these filters is performed under conditions most favorable to speed and accuracy. We are therefore glad that these beautifully constructed and reproducible light filters which are really pieces of fine optical apparatus, are made available for our use.

Dr. H. E. Ives: Referring to the remarks of a previous speaker, I would like to take this occasion to say that any color matching or radiation matching method gives us the radiant efficiency, that is, radiated watts per lumen, which may have any one of a series of relationships to the applied watts per lumen. This appears, viewed from the standpoint of photometry to be rather more logical than speaking of the black body temperature. Of course, there would be an absolute equivalence between the two. We can recognize several other methods of rating radiation. For instance, we can speak of the daylight efficiency, we can speak of the photographic efficiency, and we can even, I think, look forward to the time when we can use correction factors for certain cases which are rather common, such as the low values usual in street illumination. Personally, I see no objection at all to having one single value ascribed to the candle-power of a colored light, that being the most useful value, and recognizing that, if we are going to light a street, we must give an advantage to a Welsbach mantle as against the redder carbon lamp, one which is arrived at by experience, because I think that all of these cases where we would apply a correction factor are, after all, not only in the minority, but are those cases in which accuracy is not anywhere nearly so necessary.

In further reference to this question of setting up lamps by color matching, if I may bring up a little ancient history, a number of years ago I pointed out in a paper that in making a setting by visual color matching, one was using an extremely short lever. One is practically making a balance with two ends of a spectrum of very short range. I suggested that the logical development of such an idea was to extend the length of the lever and make a setting between one end of the total spectrum, visible and invisible, and somewhere at the other end, or, to put it in slightly different form, between the visible radiation and the total radiation. Now, at that time, anything in the line of radiometric setting would not be considered a laboratory proposition, so I reversed the proposal and described an instrument in which both the watts and candle-power were measured as light, not as energy or radiation. Since that time there have come into general use types of galvanometers, the string galvanometers,

which are not only very sensitive, but much less subject to vibration and other laboratory troubles than the instruments then commonly in use. I think that if this matter of setting for efficiency is of great importance, that it would pay someone to make experiments on a radiometric method of setting with string galvanometers. I had hoped to try these myself. Mr. Howell told us at last year's convention that the whole question of photometry was out of date in the case of tungsten lamps, because the diameter of the wire was measured, and if the photometrist could not come up to the mark he was discharged. This rather put a damper on the matter of setting lamps to efficiency.

DR. C. E. K. MEES (in reply): I assumed, when I wrote this paper, that anybody who was going to use a filter would determine its transmission. I never assumed they would take those transmissions as anything except the amount of light those filters would let through, measured on the source on which the filter is intended to be used, and they are accurate for the second figure for the conditions under which I worked; but I would not like to say that any 2 filters—this I want to be quite clear about—that any 2 filters we made are exactly alike. These filters are not so intended; they are reproducible, in the sense that their color is reproducible, in the sense that their density is reproducible, in the sense that their photometric figure is reproducible. Dr. Ives' new solution* for a primary yellow standard is a primary standard that can easily be made. The filters described in my paper are not intended for such use at all; they are secondary standards covering a large range. I want to make that quite clear, for I would not want to be held responsible for giving somebody a filter different from the one I gave somebody else, because they certainly will differ in photometric density; but they will both balance at approximately the same color, and by trial one can determine the color at which they exactly balance.

I regret to have to disagree with Dr. Ives, but when he said we could determine the photographic efficiency of a lamp, he was anticipating by several years. We cannot, because we haven't got any definition of photographic efficiency. There is no photo-

*Ives, H. E., Experiments with Colored Absorbing Solutions for Use in Heterochromatic Photometry; TRANS. I. E. S., vol. IX, p. 795.

graphic material that can be in any way termed standard. All photographic materials are made by makers who are remarkable for their reticence about their materials. I have been one for several years and I know how loathe they are and how apt they are to change their materials, either on the ground that it is for the good of the general public or for the good of themselves. Before we can determine a thing we are going to call photographic efficiency, we have got to determine something that we are going to call photography. We are at work on that in the Eastman Kodak Company's laboratory and in perhaps a year's time may tell you some of the progress we have made and suggest a possible definition even of a photographic material, and therefore photographic efficiency; but at present there is no such definition.

The reason I did not use gas-filled lamps in these measurements was that I could not get them. I wrote to Mr. Mackay and told him if he wanted us to use a gas-filled lamp it was up to him to supply the lamp. He agreed with me, but he did not supply the lamp. At the time these filters were made none was available.

I am prepared to abandon anything I have said on the second page of the paper regarding the designation of lamps: I am convinced that I have sinned in expressing those in watts per candle-power; I only intended that the figures should be some addition to the paper. I ought not to have given two figures, but, then, really, giving one figure more than you know isn't anything unusual. (Laughter.) Mr. Mackay has said if I had given them for gas-filled lamps they would not have meant anything at all, whereas by giving them for vacuum lamps they did mean something, although it is not very definite.

THE RELATION OF LIGHT TO THE PROOF OF DOCUMENTS.*

BY ALBERT S. OSBORN.
Examiner of Questioned Documents.

Synopsis: The general need of proper illumination in court-rooms is emphasized in this paper. In the trial of many cases the administration of justice or injustice often depends upon how certain visible evidence is viewed and interpreted, the examination and detection of forged and fraudulent documents for instance. Special uses of light in connection with microscopic and photographic examinations of documents to establish certain physical facts—erasures, substitutions, age and genuineness of writing, etc.—are also discussed.

I can think of no association that bears a name which affords such a temptation to the manufacture of figures of speech as an Illuminating Engineering Society. The name at once suggests the dark places that need your assistance. Every department of human activity does indeed need illuminating engineers and what we all want everywhere and all the time is more light.

Light is an important factor in the proof of documents and light engineers can promote justice by making it easier to prove the facts regarding disputed documents. Anything relating to the subject of illumination that affects the quality of human vision is of vital importance in all forgery investigations. Justice has been defeated many times because court-rooms like cathedrals have been lighted with a dim light somewhat in harmony with some of the hampering old legal precedents. Partly because of poor illumination, judges and jurors in many instances have not been able to see properly, where the case depended chiefly upon visible evidence. This partial blindness in the past has been due in some degree to an ancient legal procedure that threw a twilight gloom around legal investigations, weaving such a network of restrictions about them as made it difficult to prove a physical fact. Strange to say, objections are still made to the use of the microscope, to photographs, and aids

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

of every kind, and these objections, even in these days, are now and then sustained. All these old restrictions have been intensified by poor lighting and improper physical surroundings as well as by individual but unconscious deficiencies in seeing ability, for there is in fact a form blindness akin to color blindness.

When the necessity arises for proving a somewhat obscure physical fact by visible evidence this whole question of human vision with its defects and limitations becomes a question of vital interest. In the first place, it is important to realize that seeing ability is not by any means the same with all observers. It is an encouragement to improve our sense of sight to realize that only part of our skill comes by nature and that much comes from study and experience.

It is also helpful to consider just how it is that we actually see what we think we see. We all know that when we hear sounds we perform a mental operation and from these sounds infer certain things. From arbitrary combinations of sounds, for instance, we get an English word which conveys an idea, or from another combination a German word, and from still another combination we infer that a man is walking or a horse is running. When we see things, however, we are inclined to assume that we are receiving directly in the brain positive information instead of certain sensations which we must mentally interpret just as we have interpreted the sounds.

In much greater degree, therefore, than we are inclined to admit it is no doubt true that we really see but little more than we are able to compare with some experience or standard that we already have in the brain. The savage does not really see a steam engine, or a watch, or a city, and in some degree we are all in the savage class. The thoroughness of this mental comparison and the final accuracy of sight depends upon two things, the force and clearness of the sensation that reaches the brain and the experience which the brain already possesses. The necessity for seeing clearly, therefore, is that we may interpret accurately.

This whole question of human vision and the aids that perfect and intensify it, is naturally closely related to the question of discovering forgery and the numerous other physical conditions

that may point to fraud of various kinds in connection with disputed documents, and is of special importance in connection with the showing and proving of these facts in a court of law, often against prejudice and usually with untrained men who must be made to see and understand. It is therefore essential that sense impressions of all kinds be clarified and intensified in every way possible, and the arrangement, distribution, and management of light has a most important bearing on the subject.

Under the old legal practise, now happily but all too slowly passing away, expert testimony regarding forgery and documents, involving as it does many technical interpretations of visible evidence, was mainly the giving of bare oral opinions on a contested question in courts of law. This practise, much criticized and discredited, still continues in certain cases relating to insanity and some other subjects that the ordinary man, no matter how assisted, is unable to pass upon intelligently. A new practise, however, has developed in most jurisdictions in connection with proof of physical facts relating to documents, by which referee, judge, and jury are actually shown the basis for whatever opinion is given so that with the assistance of reason-giving testimony, now admitted in almost all courts and with the aid of instruments and enlarged, properly grouped photographic illustrations, they can finally reach their own conclusions regarding the disputed fact. Testimony is not simply oral, as in the past, but visible as well.

With the new and enlightened procedure and a court-room where seeing and hearing is possible, numerous surprising verdicts in cases of this class have been rendered. Three recent New York cases are conspicuous examples. In the first, four alleged eye-witnesses, two of them of irreproachable character, testified to the execution of a will and a jury decided it was not genuine; in the second, six witnesses testified that they saw a certain contract signed and a jury decided the document was a forgery; and in the third, a jury convicted a distinguished member of the bar of forgery of only two short words in typewriting that, by comparison, were shown to be written on his own typewriter.

It will readily appear that this change of practise regarding

visible evidence makes necessary such an illumination of court-rooms or trial chambers as makes it possible to see with the utmost distinctness. To the end therefore, that visible evidence in cases of this class, and in all kinds of cases, may be presented with the utmost clearness and force it is highly important that an illuminating engineer be consulted in regard to the arrangement and lighting of every court-room.

Another reason why court-rooms should be properly arranged and lighted is to enable judge and jury to see witnesses with the utmost distinctness as testimony is being given as well as to hear them. That this result may be attained it is necessary that witness-box, jury-box, and judge's bench be arranged in proper relations to each other and near together. Fortunately, there is in all of us a kind of instinct, enforced by conscious and unconscious training, by which we judge whether or not those who speak to us are telling the truth. This important faculty is dependant upon both the senses of sight and hearing. We recognize at once an insincere tone; even children and dogs judge us in an occult and unknown manner. By the use of the eye as well as the ear, we unconsciously interpret all messages that come to us as exaggerated, true or false. That ancient requirement of the law that "the accused must be confronted by the witnesses against him" was no doubt in some measure based upon this important faculty by which truth is separated from falsehood. A witness should be placed close to and nearly, if not quite, facing the jury or the judge who is to decide upon the truth or falsity of his testimony, and the room should be so lighted that his attitude, appearance, and every changing expression is distinctly seen. Few of us have ever analyzed the evidences of sincerity and of untruthfulness as shown by hearing and sight, but we can understand how, at least to some extent, it can be done.

A visit to many a court-room is sufficient to show how such a room should not be arranged and should not be lighted. Artistic and architectural considerations, in many cases, would seem to be the only ones that had been consulted in the arrangement. In many a city of our land, of all places, the court-room is the one place where it is most difficult to hear and the most difficult

to see, and the administration of the law could be greatly aided by the lighting engineer, the ventilating engineer, and the acoustic engineer. Trials should be held where every word spoken can be heard distinctly and where every piece of visible evidence can be clearly seen for exactly what it is.

There are many court-rooms so dimly lighted and so improperly arranged that it is almost impossible in them to prove forgery when such proof must be based upon the correct interpretation of delicate but highly significant visible evidence. In some few cases court and jury leave their accustomed places and in an informal and sensible manner gather around some low-placed, clean window where all can see and all can hear.

In connection with the proof of many different questions relating to disputed documents correct and adequate illumination is absolutely essential if the facts are to be proved. Vital evidence is sometimes based entirely upon the interpretation of indistinct stains, or delicate tints or colors which, under the dim light provided, all become a dull and indistinct gray. In cases involving chemical erasures, in which certain indistinct yellow stains are of the utmost significance, such evidence is practically invisible under the yellow, flickering artificial light or the dim daylight of the average court-room. In many court-rooms the effective use of a microscope is simply impossible.

In many cases involving the identification of paper, where sheets have been interpolated in disputed documents, the case could be positively proven out in the court-yard, but under the conditions provided, intensified by the bad acoustic properties, injustice may triumph or the guilty may escape. Many a city in this land has spent millions of dollars on a court-house without one properly-lighted and well-arranged court-room where clear seeing and distinct hearing are possible. Darkness and evil have always been associated and still are associated in many a court-room. The modern laws of some states happily require a certain amount of properly placed light in every school house, but such laws, it would seem, have not yet been applied to the law houses.

Light is also a great aid to justice in connection with the subject of photography as now applied to the investigation and

proof of disputed documents. To the modern examiner of disputed handwriting and documents the photographic camera bears a relation to the business similar to that of the compass to the mariner. The relation of light to this question of photography is as close as the etymology of the word itself suggests. It writes out in a universal language its unmistakable interpretation of many things. Many disputed document cases are hastily settled as soon as they are properly illuminated by the photographic camera.

The camera assists us to see certain things which without its aid are too small for us to recognize in their true significance and force. It is one of the natural but erroneous human assumptions that we see all that exists before us, but we know that this is not true, and thus arises the necessity in connection with many questions of properly enlarging the thing to be observed. Many forgeries are perfectly apparent when enlarged a few diameters. The photograph also makes it possible to cut apart, group, and arrange the parts of a disputed document for effective study and comparison.

As is well known, the whole photographic art is based upon the arrangement and control of light and certain hidden facts in a forgery can be clearly shown in a photograph by certain special arrangements of light. In a laboriously perfected forgery in which the lines have been carefully retouched and overwritten so that under ordinary vision the result seems to be perfect, a transmitted light photograph under proper enlargement is often sufficient to prove the fraud. By this means the varying thicknesses of the ink film itself are measured by measuring its ability to transmit light. If a line is retouched skillfully so that the edges are not broken or disturbed such additions under ordinary vision may be invisible even under magnification, but a transmitted light photograph of such a stroke, enlarged from four to ten diameters, will show in permanent form with the utmost distinctness every added stroke. In making a photograph of this character the document is lighted partly from the front, but with the strongest light from the back so that the light which makes most of the photograph is actually transmitted through the paper itself.

The transmitted light photograph is often more effective than the microscope to show retouching but for preliminary investigations of this kind and also for direct demonstration in court the following special application of light is of great aid. A microscope table with a glass top having a strong light close underneath is provided. This combination is very useful, especially when employed in connection with the stereoscopic microscope. An arrangement of this kind in the leading banks of the land, available for instant use, would save thousands of dollars every year as by its aid an experienced observer, in many cases, is literally able to "see through" a forgery. By this means light is literally thrown on the subject.

Another condition under which special illumination is of great value is in the interpretation of certain kinds of erasures. especially erasures of pencil lines. The disposition of thousands of dollars may depend upon the interpretation of a few words or even a few figures and the determination as to whether or not they have been changed. Unlike an ink line, an ordinary pencil mark is made by sufficient pressure on the writing instrument so that a certain amount of graphite is worn off against the surface of the paper. If a mark of this nature is carefully erased so that the coloring matter is removed, it may become entirely illegible although the depression still remains, but is so shallow that it is invisible even under the microscope. If, however, such an erasure is photographed in enlarged form with a strong illumination through a narrow slit on one side with the rays of light almost parallel with the surface of the paper, the shallowest depression, where a word or figure has been so effectually erased that it is totally invisible under any other examination, then produces a shadow which, in a photograph of this kind, sometimes shows with absolute distinctness what was originally written.

Another class of cases under which the question of perfect illumination is of vital importance is in all ink investigations either to determine age or to discover whether two or more ink writings are identical or different. Some of these questions can no more be answered under the illumination of certain courtrooms than they could be answered in the light of the average

cellar, while the same investigation if conducted under properly diffused white light shows a result that can be seen and appreciated by any intelligent man. It is easy to understand how desirable it may be under certain circumstances to show that writing is not as old as it purports to be, or to show that an addition or interlineation in ink is the same or different from other parts of the same document. The interpretation must be based mainly upon the recognition of certain colors. Under suitable conditions and proper lighting this recognition is possible with the average observer. In many court-rooms such facts cannot be proved.

All ordinary commercial ink of the present day is a chemical solution to which a temporary blue color is added so that the writing may be legible when first written. Fresh writing of this kind, as we are all aware, is of a distinct blue or bluish green color which color gradually disappears as it it submerged or masked by the development of a stronger color from the chemical constituents of the ink, until it finally reaches a black or neutral gray. When used during the winter months modern ink, under the usual conditions under which writings are kept, requires many months to lose all its initial blue color so that examinations like those described, to show that the ink is not as old as it purports to be, may be made a long time after the actual date of the writing. Wills and documents representing hundreds of thousands of dollars are brought into courts of law purporting to be many years of age on which the ink color has not yet reached its ultimate degree of blackness or intensity.

By the use of a special color microscope with two objectives and the Lovibond tintometer glasses it is possible to match and record this changing ink color with great accuracy. For example, it is easily possible to match more than a thousand variations in the color blue alone. If an ink of this class is accurately matched and recorded as it first appears on a document purporting to be several years of age and then the same portion of ink is observed under the same conditions a few days or weeks afterwards and the ink has distinctly changed from a blue or distinct purple to a black or a much darker color, this is positive proof that such document is not as old as it purports to be.

Most persons can recognize colors under favorable conditions but the recognition and matching of colors in an investigation of this kind in the ordinary court-room under the conditions ordinarily provided, is simply impossible. If evidence of this class is to be made use of, it is necessary that the ink should be observed under diffused white light of the proper intensity.

Another most interesting special application of light that promises to assist in disputed document cases makes use of those strange new rays of the spectrum out beyond the violet. By the use of a suitable screen and appropriate illumination it is possible to photograph totally invisible stains resulting from a chemical erasure so that the original writing becomes entirely legible.

Thus we see the advancement of knowledge in every field supplements that in every other field and light engineers may be of great service in illuminating unexpected dark places in various divisions of human activity.

DISCUSSION.

Dr. P. G. Nutting (Communicated): All of us who are interested in the problems of special lighting, image focussing instruments or photography will be grateful to Mr. Osborn for discussing the problems of his very interesting specialty. He raises again the old question as to the truthfulness of the microscope, the copying lens and of the photographic process.

My acquaintance with Mr. Osborn began ten years ago when I wrote Bureau of Standards Certificates for his copying lenses. These certificates were to be produced in courts of law in evidence (in effect) that the said lens did not render in the copy anything not in the original:

Wildly absurd as it seems to us to be required to prove that a copying lens does not *create* details in the copy, is it so preposterous after all? A lens can tell *less* than the truth, may it not tell *more?* A microscope presents details much too fine to be observed by unaided vision, may it not show what is not in the original at all? Can we photograph what we cannot see? What could not be seen with the most favorable illumination or magnification? Under what conditions is a photographic copy a sensibly exact reproduction of the original?

Dim, ill-directed lighting suppresses details; might not skilfully manipulated lighting show details that do not exist? By photography, contrasts may be greatly enhanced, might not objects appear in a print which could not be seen by the eye with any sort of illumination of any chosen quality? Would anyone of us undertake to tell the exact truth, on the witness stand, in reply to such simple questions as these? We cannot but sympathize with the expert who must attempt it.

Courts of law require first of all assurance of the *existence* of objects at issue. To this we do not hesitate to reply that where detail is seen, detail exists; a homogeneous object free from detail will appear without detail whether viewed directly or viewed or photographed through a lens or lens combination. The converse is, of course, *not* true; detail may be present but not apparent.

Details may be suppressed by a number of familiar means; by too low and too high illumination; by lack of focus in the copying lens; by lack of resolving power in the retina, projecting lens or photographic plate; by illumination so directed as to give no shadows; by color filters suffusing contrasts; by over or under exposure of the photographic copy. Details may be enhanced by similar familiar means, many of which have been mentioned by Mr. Osborn.

Suppose we take as absolutely correct rendering, from the point of view of judge and jury, (*a*) the reproduction of *all* details above a certain microscopic fineness and (*b*) the rendering of contrasts in a degree *realizable* to the eye by a judicious choice of illumination. The human eye being thus a competent judge of fact, the microscope, copying lens and photographic plate of the expert if properly used always tell the truth but cannot *create* or tell more than the truth.

Mr. F. E. Cady: I would like to ask Mr. Osborn whether these same ideas which he has presented with regard to documents would not hold also with regard to the identification of individuals? Perhaps that may be a little out of your line, but I have understood from papers which I have read, that there is often a great difficulty on the part of witnesses in identifying individuals, two witnesses giving exactly contrary testimony.

Might not that in many cases be due to deficiencies in the lighting conditions?

Mr. J. B. Taylor: This paper has certainly been a great treat and bears out the old saying that truth is stranger than fiction. I wish we might see more of Mr. Osborn's slides with more time for each. The explanations of the critical analysis and incidents would put some of the Sherlock Holmes accomplishments to shame.

The particular point in the paper that I wish to discuss is the introduction of photographs as evidence. The paper refers to objections which are frequently made to such evidence and doubtless this comes about largely through the common saying that "photographs cannot lie," supplemented by any quantity of examples that the veriest tyro in photographic work can produce with distorted perspective, multiple exposure, multiple printing, etc.

In studying an object, or combination of objects, we receive our visual impressions from *form, color, illumination* or *brightness* and *relative positions.* Now the ordinary photograph shows the *form* fairly well, (provided the lack of color differentiation does not fail to show the boundary lines between objects of different color), the *colors* not at all, the *brightness* imperfectly and even erroneously, unless panchromatic plates with proper filters are used, and the *positions* only partially because the picture is flat. Hence for many cases the best and proper record is a color-photograph. If in addition the color-photograph is made with a stereoscopic camera the record is as nearly complete and correct as present state of the art permits.

It is a surprise to one who has made no study of stereoscopic possibilities, how much can be seen with the usual monotone black and white stereoscopic picture and how much more can be seen by the color-photograph stereoscopic picture.

It is of course possible to get distorted stereoscopic results; in fact possibly nine-tenths of the stereoscopic pictures which are circulated and in use are distorted in the sense that depth (apparent separation of objects from front to back) is exaggerated. Much stereoscopic work has been and still is done with the camera lenses on centers greater than those of the eyes—the normal separation

of the eyes is 62 or 63 millimeters, and in order that the camera will record the view as a man sees it, materially different lens distances are not permissible.

In addition for critical stereoscopic results other conditions must be observed of which one is a proper relation between the focal length of camera lenses and focal length of stereoscope viewing lenses. These can not now be further discussed, but if all are attended to, there is set up the same angular relation for the pictured objects for the right and left eyes as in the original

I will pass around a stereoscope with a color-photograph (autochrome) slide taken to show a piece of machinery. This was made because certain patent conditions might arise calling for a record of the manner in which the apparatus was set up at a given place and time.

Dr. H. E. Ives: In this discussion of stereoscopic effects, I just want to mention something I saw the other day at a moving picture show. This was announced as a special patented system of the moving picture company. You all know the problem of showing stereoscopic pictures on a screen is one that can only be solved by special apparatus which is not at all practical. I was interested in this announcement and during the progress of the showing of the pictures I realized that occasionally they were getting stereoscopic effects, with one single point of view. The way it is done is very simple and probably arose from a chance observation. When the picture taking apparatus was slowly moved across the field all the objects nearby were apparently moving at a different rate from those at a distance, and immediately the beautiful Ionic pillars and so on that were part of this ancient moving picture scene stood out solidly on their backgrounds. As long as they were moving, one realized their arrangement in space. I thought that perhaps some of these relative positions of different parts of the object of interest to Mr. Osborne might be brought out by using moving pictures and utilizing that device of slow lateral motion.

Mr. L. B. Marks: The remarks of Mr. Osborn are of the very greatest importance to illuminating engineers who have in hand the task of designing the illumination of court rooms. It occurred to me while Mr. Osborn was speaking that it might be

a good plan, in some cases, to superimpose light on the face of the witness; that is to have a general illumination of the court room and then to superimpose light properly directed on the face of the witness.

Mr. Albert S. Osborn: A spot light?

Mr. L. B. Marks: An approach to it. Unfortunately we are somewhat restricted in this direction, but I believe that such a plan may be carried out.

THE LIGHTING OF ROOMS THROUGH TRANSLUCENT GLASS CEILINGS.*

BY EVAN J. EDWARDS.

Synopsis: This paper is a brief report of a study of the factors entering into the design of lighting systems for special rooms having ceilings of translucent glass with the light sources placed above the ceiling. The results of photometric and other measurements on several sample glasses are set forth.

The lighting of special rooms through translucent glass ceilings has been a difficult task from the standpoint of design due to the lack of data regarding the properties of various available glasses. The results to be accomplished are, of course, the proper lighting of the room, with the best possible efficiency and generally with little or no spotting effect on the ceiling itself. The best results have not been accomplished in many of the installations which are now in use, and it is reasonable to expect that many of these failures are due to the fact that the designer did not have sufficient knowledge of the characteristics of the glass which he used. Of course there are instances where the illuminating engineer was called in after the glass was in place and the space limitations above the glass were already fixed.

The work, a report of which this paper is intended to cover, was begun in order to get a better understanding of the features involved as well as to determine the characteristics of various available glasses.

To eliminate a spotted effect, the glass must be more or less diffusing. The less diffusing it is, the narrower must be the spacing between the units or the higher above the glass they must be placed. Also the greater the diffusion, at least with the character of diffusion obtained with ordinary opal glass, the lower will be the efficiency of transmission. A proper design must therefore show the right balance between these various features, so as to get the best possible results under given con-

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

ditions. If the hanging height cannot be high on account of the design of the building, the glass must spread the light more than in the case where the designer is free to hang the units as high as he wishes.

It was expected that, in order to eliminate spotting with a given glass, the ratio of spacing to mounting height would be a constant, and that this ratio would vary only with the kind of glass used. In order to prove or disprove this supposition, various specimens of glass were set up in front of four automobile headlight lamps equally spaced. The position of the glass with respect to the lamps was varied until the point was reached where there was no appreciable lack of uniformity of brightness. This was done with several combinations of glass and for various spacings of lamps. Then the test was repeated using regular 25-watt lamps end on, in order to get the effect of changing the size of the light source and character of distribution. The results of these tests are shown by the curves of Fig. 3. The obvious conclusion is that, so far as the purpose of the kind of design in question is concerned, this ratio of spacing height to spacing is constant. This is shown by the fact that the curves are approximately straight lines passing through the origin. That the results with the 25-watt lamps so nearly correspond with those obtained with the automobile headlights shows that the ordinary differences in source size and character of the distribution from the units will make no serious difference in the results. Establishing this one fact, very greatly simplifies the problem of ceiling lighting design, for the ratio can be determined once for all for a given glass.

The several glasses tested are designated by number and reproduced in Figs. 2 and 3. Where numbers are missing the pattern is that of the preceding number but with the variation shown in the column "character of glass." The photographs were taken at the setting of lamps which gave the mounting height to spacing ratio necessary for elimination of spotting as shown in Table I unless otherwise noted.

The remainder of the problem then is to consider the efficiency of transmission and the character of distribution: In order to determine these, the apparatus shown in Fig. 4 was built. It will

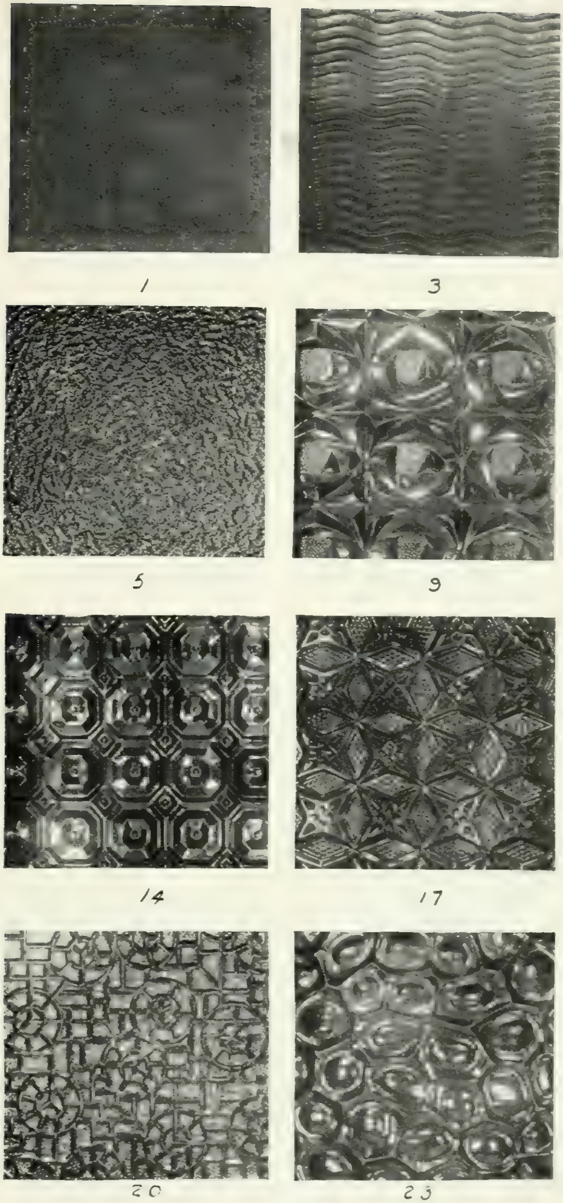


Fig. 1.

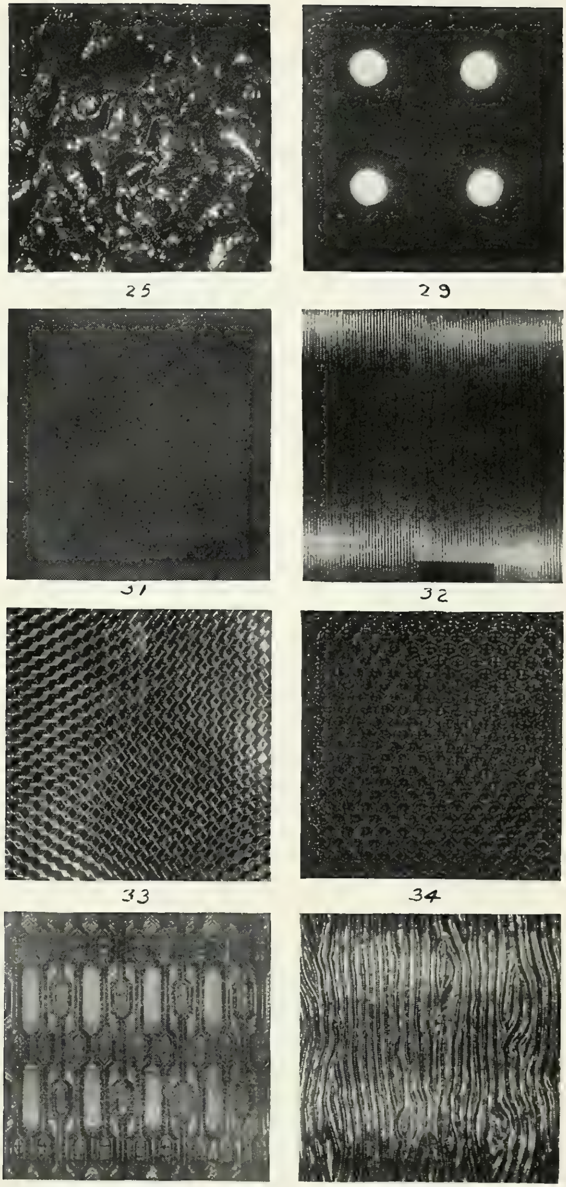


Fig 2

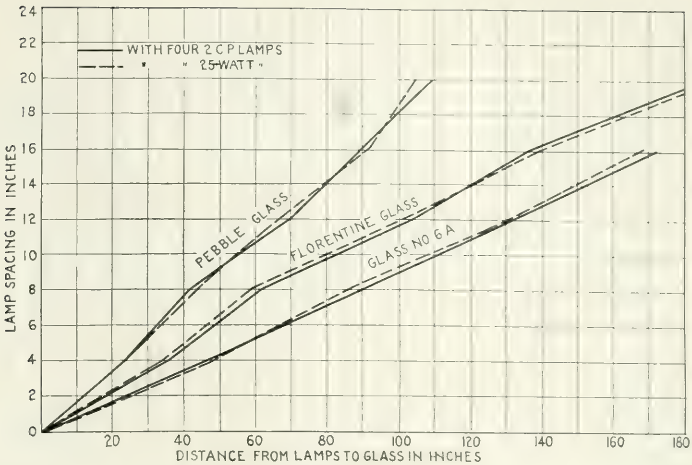


Fig. 3.

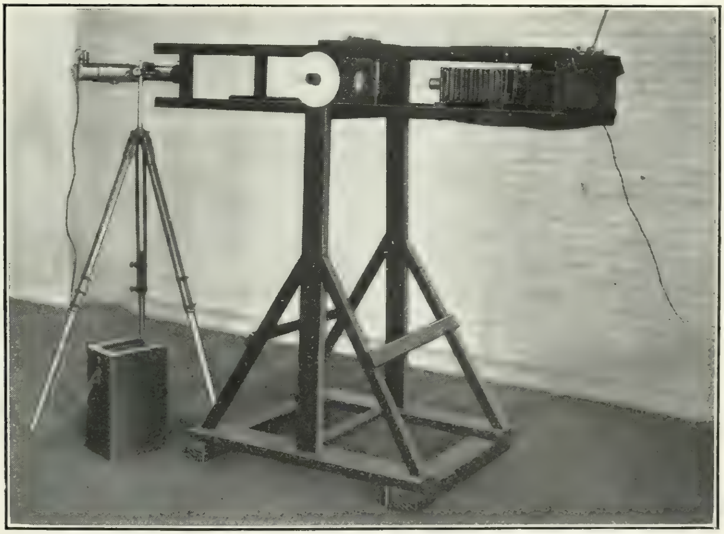


Fig. 4.—Apparatus for measuring light transmission of glasses.

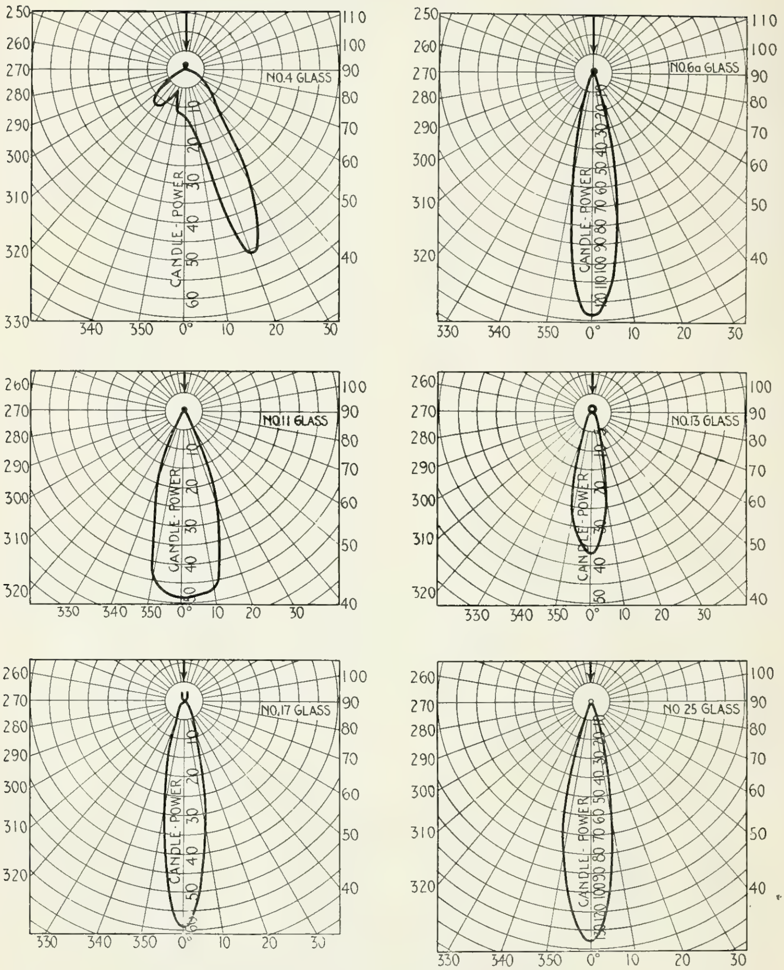

NO.4 GLASS
CANDLE - POWER
NO.6a GLASS
CANDLE - POWER
NO.11 GLASS
CANDLE - POWER
NO.13 GLASS
CANDLE - POWER
NO.17 GLASS
CANDLE - POWER
NO 25 GLASS
CANDLE - POWER

Fig. 5.

be seen that the glass specimen is supported so that its plane lies within the axis of a trunion in such a way that it can be revolved

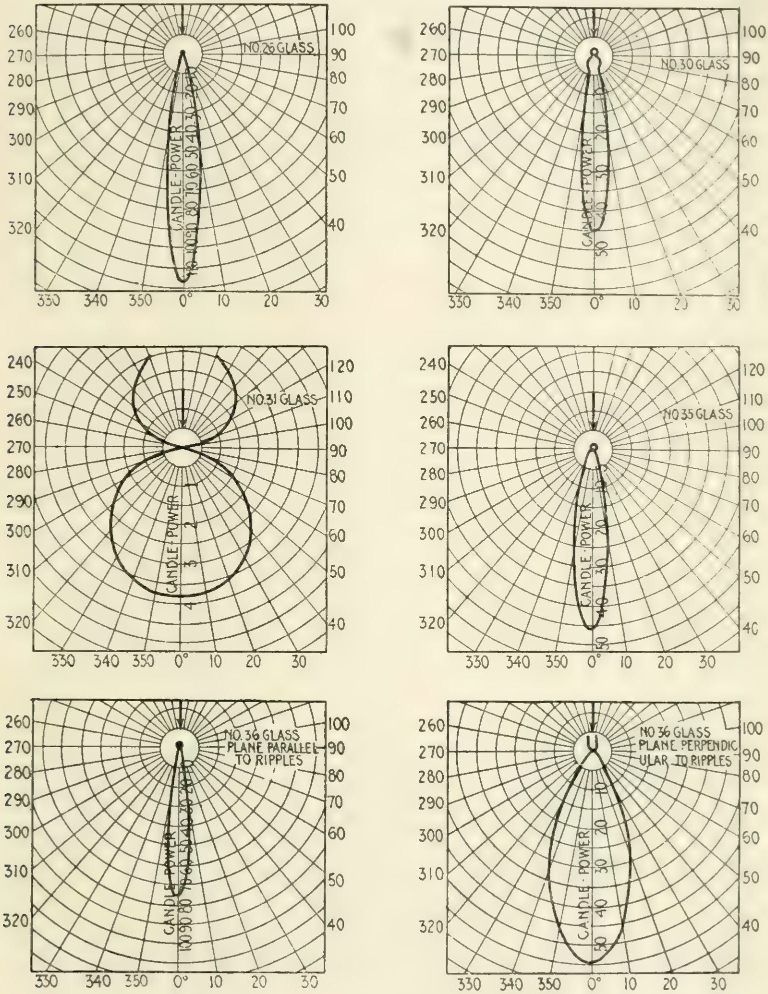


Fig. 5a.

through 360 deg. A parallel beam of light is projected normally on the specimen by means of a lens combination which remains in a fixed position with respect to the specimen. Intensities in all directions are measured by means of the Weber portable

photometer. Having obtained intensity measurements in all directions, the character of distribution of course becomes known, and it is a simple matter to compute the efficiency of transmission and also the total quantity of light turned back by the glass.

TABLE I.

No.	Mounting height to spacing distance ratio necessary for elimination of spotting	Transmission efficiency per cent.	Character of glass
1	19	45	Light opal
2	*	46	Yellow and iridescent
3	3	39	Opal
4	4	65	Clear
5	2	35	Very light opal
6 & 6a	11	63	Clear
7	8	44	Yellow
8	5	43	Opal light
9	2	54	Clear
10	2	33	Opal
11	3	50	Clear
12	2	40	Yellow
13	3	29	Opal
14	3	36	Clear
15	3	37	Opal
16	2	22	Violet
17	3	41	Clear
18	3	39	Yellow
19	3	30	Opal
20	2	34	Clear
21	4	28	Opal
22	3	18	Dark yellow
23	4	41	Clear
24	4	31	Opal
25	4	66	Clear
26	4	46	Opal light
27	3	37	Yellow
28	3	35	Opal
29	*	36	Opal
30	*	35	Opal
31	2	28	Opal
32	*	69	Clear
33	*	45	Clear
34	3	36	Clear
35	5	35	Opal
36	15	57	Clear

* Impossible to eliminate spotting with any reasonable ratio.

Distribution curves were taken on all of the specimens listed in Table I, but on account of the lack of space, only a few of the more significant ones are shown in Figs. 5 and 6. Table I shows the transmission efficiency for all the glasses tested. For those having an assymmetrical distribution, the zonal intensities were taken as the average of those obtained in two planes 90 deg. apart. This method may lead to some inaccuracy, but the amount of work involved to obtain higher accuracy did not seem justified.

Perhaps the most striking result of the photometric tests on these glasses is the great difference in transmission efficiencies. The crystal glasses, those which spread the light by irregular refraction have tremendously higher transmission efficiencies than those which spread by the kind of diffusion which is obtained in opal glass. It appears from the results that an irregular crystal glass on the order of specimens Nos. 25, 9 and 6 is the best to use in translucent ceiling lighting. The spotting effect can be easily eliminated and at the same time the transmission efficiency can be made comparable with that obtained with lighting fixtures.

The author desires to acknowledge the assistance of Mr. C. J. Berry who conducted the tests, and Mr. Edgar H. Bostock who furnished many of the samples of glass tested.

DISCUSSION.

PROF. F. C. CALDWELL: With regard to the difficulty involved in using the same glass both for natural and artificial light,—attention might be called to the use of a double skylight where space permits, with a glass of high absorption in the outer skylight to reduce the intensity of the daylight and a glass designed especially for the best effects for the artificial illumination in the lower skylight. This plan is of course only practicable where there is an opportunity to use a spacing of several feet between the two skylights.

MR. S. G. HIBBEN: Would it not be advisable to continue these experiments to ascertain the relations between thickness and diffusion of some of these glasses? It seems possible that power of diffusion may increase with thickness, but without

having a corresponding increase in the absorption or in the transmission losses.

I do not believe I have ever seen published any authentic data to show whether it is cheaper to produce an amber color by using colorless glass and burning the lamps at low voltage, or whether it would be better to employ amber colored glass to screen out the white light from lamps burning at high efficiency.

The choice between the two kinds of glass, opalescent or crystal roughed, depends entirely on the use to be made of the false ceiling or skylight. The limited space above a glass ceiling for placing light sources, makes it impossible to secure uniform illumination of crystal roughed or rippled glass unless a prohibitively large number of closely spaced small units be used. Again, some cases require daylight lighting, with highest possible transmission, and this favors the rippled glass.

Direction of light depends on the glass. For two illustrations I cite (1) the Albright Art Gallery in Buffalo, which, when I last saw it, was lighted through a ceiling of crystal roughed panes, and (2) the palm room of the Ritz-Carlton in New York, with its false ceiling of white glass tile. In the first case (with spread transmission) the light is directed against the walls by reflectors set at an angle above the ceiling panes. This is as it should be. In the second case (with diffusion—maximum intensity, normal to the plates regardless of the angle of incident light) the light is directed downward, where it is wanted.

Where daylight is not to be provided for, a diffusing surface may be used above a false glass ceiling of crystal-rippled or similar non-diffusing plates. For instance in the Soldiers' Memorial Building at Pittsburgh, the arrangement is as shown by Fig. A. Lamps are placed in an opaque white-interior metal box. Beneath rows of lamps are hung dense opal glass troughs to cut off direct rays, and the false ceiling is of very light amber tinted ripple glass. It is an inefficient means when now-a-days one can procure diffusing opalescent sheet glass that prevents bright spots, but without prohibitive absorption.

Lighting through false glass ceilings is not expensive when considering that such a system, having a loss of 35 per cent. to 40 per cent. over that of direct lighting, can now be used where

nitrogen-filled tungsten lamps are employed. These lamps will give easily as much more light than the one-watt-per-candle tungsten (vacuum) lamps, as is lost in ceiling glassware. The

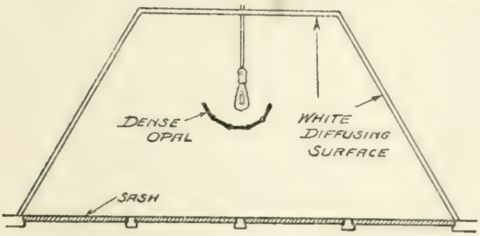


Fig. A.

efficiency of lighting through false glass ceilings compares closely with indirect lighting, when the same efficiency lamps are used.

Mr. E. B. Rowe: Mr. Edwards' paper deserves a word of appreciation as a contribution of reliable data which we have lacked in the past. We have had very little data available on the characteristics of the transmission of light through translucent glass for skylights and ceilings.

I believe Mr. Edwards' opal glasses, and I should like to have him correct me if I am wrong, were all flashed opal. It has shown that a light density opal can have a much higher transmission. The appearance of glasses when used as skylights will always be a matter of opinion. There are people who do not like the appearance of crystal glasses of any kind and prefer opal. To some an opal glass is flat and monotonous, while a crystal glass has some "life" in it and is more often in harmony with its surroundings.

The use of the proper *crystal* glasses seems specially necessary where there is not only needed high transmission of the kind such as a previous speaker called regular transmission, *i. e.*, where the distribution of the transmitted light can be controlled, but also where transmission without alteration in color is desired. A problem in lighting through skylights which I recently worked on involved both these factors.

It seems to me that there are a great many cases where sheet crystal glass of the proper design will give to all intents and purposes the equivalent of opal diffusion, and possesses important additional advantages over any opal glass.

Mr. E. J. Edwards (In reply): A previous speaker seems to favor opal glass for ceilings. I will agree that there are some places where an opal glass would work out better. The paper was intended not to favor one kind of glass to the exclusion of the other, but rather to point out the main features involved in design. Where opal glass is used the light sources themselves furnish light to the glass ceiling, and the glass ceiling in turn lights the room. But unfortunately the opal in becoming a secondary source illuminates in all directions; and when it is necessary to add to the losses of light between lamps and the glass ceiling the one-half factor of loss due to the glass lighting the attic as much as the room below the resulting over-all efficiency is very low. With crystal glass the ceiling itself is not a secondary light source; it serves only to scatter the light which is being transmitted, and on account of this scattering may give the same effect as if the light originated in the glass. An inspection of any of the distribution curves of the crystal glasses will furnish at once the explanation of their high efficiency as transmitters. There is very little returned light.

Mr. Rowe has suggested that the trade names of the glasses tested be given as designations. In answer to this it is only necessary to say that the paper is not a comprehensive study covering all available kinds of glass, and therefore fails to direct attention to many excellent glasses which may be available but not included in the tests.

The three opals used were flashed opals, the only difference being in thickness of coating. As a previous speaker has pointed out, it is impossible to eliminate spotting until the thickness of opal is sufficient to prevent any direct transmission of light. The thin and medium opals of the tests allowed considerable direct light to pass through. In using an opal glass where spotting must be eliminated, it is necessary to use something as thick or nearly as thick as specimen No. 31.

Regarding the question of appearance, brought up by Mr. Rowe, I am inclined to favor the effect produced by coarse crystal glass. There is a "life" to a ceiling of crystal glass that you do not get with opal; of course, here again, it all depends on the case in hand.

A very important question concerning the behavior of glass ceilings in the daytime has been raised by one speaker. He pointed out that the transmission of daylight must not be of such high efficiency as to make the room too bright during the day. Practically all installations of glass ceilings are arranged with an upper skylight, with the artificial lighting units hung in the space between. In order to properly control the amount of daylight which enters the room, it is only necessary to consider the upper skylight. The glass ceiling should be made as efficient as possible from the standpoint of transmitting the artificial light, and then the amount of daylight controlled by properly choosing the glass for the skylight, or by providing curtains to cut it down to the desired value.

A certain very definite thickness of opal glass must be obtained if spotting is to be eliminated, and there would be no object in making the glass any thicker. Mr. Hibben suggests the possibility of using an amber-colored glass where a very soft light is desired. It is true that light of the same color quality as that of carbon-filament lamps can be produced much more efficiently with tungsten-filament lamps and amber-colored screens than it could be by reducing the filament temperature. The ratio of efficiency for the two cases would be roughly two to one.

Another speaker seems to assume that for average conditions you must be content with either a spotted effect or a very high absorption; such is not necessarily the case. It is possible to eliminate spotting and obtain a high efficiency of transmission even where the hanging height cannot be great. In a crystal glass the efficiency of transmission is very high, provided the glass is of such a character that very little total reflection can take place. The surface may be very rough, and the best all-around crystal glass is the one which is rough in the most irregular manner, provided only that there are no surfaces which make extremely large angles with the average plane of the glass.

Referring to Prof. Caldwell's contribution to this discussion, I wish to suggest going a step further than simply adjusting the upper skylight to the proper degree of absorption. The upper skylight might also be used as a filter to bring the daylight to the color of the artificial lamps. By using a proper amber-colored

glass in the skylight it would be possible to have an illumination in the room below which would be practically uniform as regards color and intensity for both day and night. There is a great deal being said these days about modifying artificial light to the color of daylight. I believe that there are great possibilities of use in a daylight which has been modified to the color of artificial light, thereby bring about uniformity of color between the hours of daylight and artificial light. Spaces above the show windows in stores can be provided with crystal glass having an amber tint, so that the light received through the windows in the daytime will be of the same color as the artificial light being used for the interior. The artificial light in the interior of the store would not appear yellow under these circumstances and in most cases the daytime appearance would be much improved.

THE PHOTOMETRY OF GAS-FILLED INCANDESCENT LAMPS.*

BY CLAYTON H. SHARP.

Synopsis: This paper treats of the difficulties and peculiarities met in the photometry of the new lamps. First, the color difference trouble is mentioned and the method of obviating it by light filters is discussed. Second, the flicker on the photometer disk due to the interference of the loops of the filament when rotated is pointed out, and a method of obviating the trouble is shown. Third, a new effect which consists in the variation of the candle-power and watts with the speed of rotation is described. It is shown that the candle-power may change as much as 15 per cent. because of the rotation of the lamp, and that a change is observable also when the lamp is measured tip upward instead of tip downward. Fourth, the advantages which would result from rating these lamps in total lumens rather than in watts or in candle-power are pointed out and the adoption of this method of rating is urged.

The introduction of the high efficiency lamps in which the filament is surrounded by an inert gas has given rise to certain photometric problems some of which are peculiar to these new illuminants. These problems and the solution of them are considered briefly in this paper.

COLOR DIFFERENCE.

The very much greater whiteness of the light of the high efficiency lamp as compared with the vacuum lamp at normal efficiency introduces a familiar photometric difficulty which requires a practical solution. The best solution would seem to be to employ a suitable light filter so that the two sides of the photometer screen are illuminated with light of the same color. At the risk of going over ground which has already been covered in the TRANSACTIONS of this Society,[1] it may be worth while to summarize this important matter in this connection.

Light filters may be of either one of two kinds, namely a bluish filter, by means of which the light from the 1.25 w. p. c. comparison lamp is changed in the direction of white until it

* A paper read at a meeting of the New York Section of the Illuminating Engineering Society, November 12, 1914.

[1] See in particular paper entitled Light Filters for Use in Photometry, by C. E. K Mees, TRANS. I. E. S., No. 9, vol. IX.

matches the light of the high efficiency lamp, or the filter may be of a light pinkish amber, by means of which the light of the high efficiency lamp is given the necessary reddish tinge, causing it to become like light of the vacuum lamp. Of these two classes of filters, the second has the advantage that it reduces, by absorption, the light of the lamp which is naturally more powerful rather than the one which is weaker. The disadvantage is that the coefficient of absorption of any selective transmitter, such as the filter is, necessarily varies with the color of the light which it transmits. For example, when a white light is passed through a filter which removes some of the bluish components, the percentage of absorption depends upon the relation of the amount of bluish components to the amount of reddish components in the source itself. Hence with a whiter light, that is, one in which the bluish components make up a larger percentage of the total, the effect of a filter which removes a portion of the blue is greater than would be the effect of the same filter on light which is not so white. The high efficiency lamps are not uniform in efficiency but vary according to the current for which they are intended, the higher current lamps being also higher efficiency lamps. Therefore a light filter which would show a given coefficient of absorption with a 20-ampere lamp would have a slightly different coefficient of absorption with a 7.5-ampere lamp. At the same time the difference in color is not very marked on the photometer, so that they might both be photometered with the same bluish screen interposed between the comparison lamp and the photometer. As the comparison lamp is always operated at the same color, complications due to variations in the coefficient of absorption do not arise. The use of the bluish screen therefore, while it cuts down the intensity of the weaker source, has at least a theoretical advantage over the use of the amber screen.

The calibration of light filters for this purpose involves the direct comparison of lights of different color. It is therefore an operation to which the various devices of heterochromatic photometry apply. The most practical way to carry out a calibration of this sort seems to be to take the average of the photometric settings of a large number of skilled observers, made under different conditions as to illumination, type of photometer, etc. In

this way it is reasonable to suppose that the personal element is largely eliminated and a comparison based on the effect of the light on the average eye obtained. It is very gratifying to know that the Bureau of Standards is in process of establishing, in co-operation with the leading photometric laboratories of the country, a series of standard filters. The absorption values assigned to these filters will be based on measurements taken by skilled photometrists in the various laboratories and will hence presumably approach very closely to the best obtainable value. Henceforth, color difference photometry may be done with the aid of filters calibrated by direct or indirect comparison with these standard filters and in this way uniformity in this class of photometry will be established throughout the country.

FLICKER DUE TO ROTATION.

It was soon discovered in the photometry of the gas-filled lamps that the ordinary procedure of rotating the lamp about a vertical axis to obtain its mean horizontal candle-power must be applied with certain limitations. The filaments, as is well known, are coiled in small spirals or helices. The diameter of the helices is large compared with the diameter of the lamp filament itself. These helices are attached to their supports in such a way that one helix may quite completely cover another in a certain position of the rotation. Hence when rotated slowly, for the purpose of getting the mean horizontal candle-power, the variation of brightness of the photometer screen is very large; that is, there is an excessive apparent flicker of the lamp. As has been pointed out by Dr. Hyde, when a flicker becomes large, the errors of photometric setting becomes relatively enormous; it is only with a moderate degree of flicker that accurate settings can be made. So it was found with these lamps that slow rotation gave photometric settings which varied within wide limits, due to the inability of the eye under these conditions to make an accurate time integration of the brightness of the side of the photometer disk turned toward the gas-filled lamp. Obviously, this flicker would be greatly diminished if the speed of rotation could be made quite large but for practical reasons, taking into consideration among other things the size of the lamps, it is not desirable to do this. Hence in the Electrical Testing Laboratories the expedient was

adopted, which has been pointed out by Dr. Hyde, of placing behind the lamp two mirrors at an angle of approximately 120 deg. Since these lamps are quite large the mirrors also need to be of considerable dimensions and hence it is advisable to use a considerable distance between the lamp and the photometer. The photometer then receives light from the lamp directly and light from two other directions by reflection in the mirrors, and these directions are equally spaced in the circle, that is, 120 deg. apart. Obviously, the distance between the lamp and the photometer disc must remain fixed and the variation of intensity required for making the photometric settings must be accomplished by some other means. In practise the simplest and most satisfactory way is to move the comparison lamp along a track. Using this arrangement, the photometry of these lamps is no longer affected by flicker troubles even when the lamp is rotated very slowly.

CANDLE-POWER VARIATION DUE TO ROTATION.

It was discovered by Mr. W. F. Little of the Electrical Testing Laboratories that both the watts consumed and the candle-power of a gas-filled lamp vary with the speed with which it is rotated. It was found also that with the lamp operated tip upward these variations were in general much larger than with the lamp operated tip downward, also that the candle-power of a given lamp was not necessarily the same in these two positions. The variations so found are shown in the accompanying diagrams of Figs. 1, 2 and 3. It will be noted that these variations are most erratic and often attain large values. It is a comforting fact that this effect is reasonably small while the lamp is rotating slowly tip downward, that is, in its normal position of operation. From this it is to be concluded that the horizontal candle-power of such lamps should be taken only in this position, with low speeds of rotation and with a suitable mirror device to prevent excessive flicker. If higher speeds are employed the candle-power may vary to an unknown degree. It is to be noted also that the resistance of the filament varies with the speed. An increase of resistance accompanies a decrease in watts in the case of lamps held at constant voltage and an increase in watts in the case of constant current. We see therefore that the multiple

lamps driven at higher speeds give greater candle-power with smaller power input; that is, have a higher efficiency.

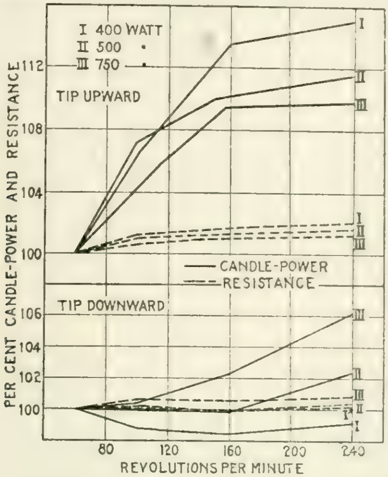


Fig. 1.—Variations in candle-power of a gas-filled multiple tungsten lamp with speed of rotation.

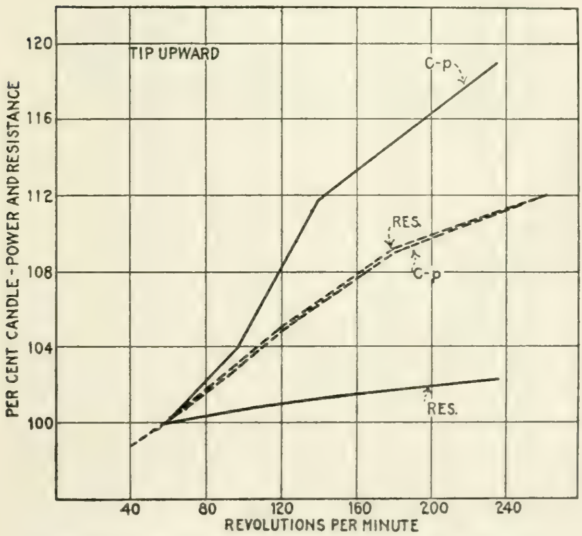


Fig. 2.—Variation in candle-power of a gas-filled series tungsten lamp with speed of rotation.

Quite apart from its practical significance to the photometrist, this is of great interest to the physicist, who is led to inquire

into the cause of it. There are several possible explanations. One is that the contact between the filaments and their anchor wires is altered by rotation in such a manner as to decrease the filament losses by conduction of heat and hence to increase the lamp efficiency. Another that the convolutions of the filament are altered so as to decrease convection losses. This would require the spirals to tighten up through rotation, whereas the opposite action would seem to be the most likely result of the centrifugal force. Of course the loops of filament may be thrown out so as to increase the horizontal candle-power at the expense of

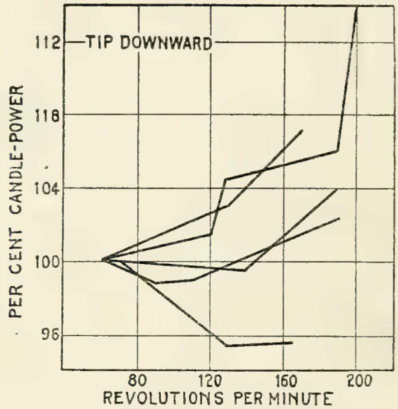


Fig. 3.—Variation in candle-power of a gas-filled series tungsten lamp with speed of rotation.

the spherical and this would account for the effect. Finally, the currents of gas which are an important factor in carrying off the heat of the filament and dissipating its energy may be so disturbed in their course as to cause a diminution of these losses and hence a higher lamp efficiency. Without further experimental research it is impossible to say what the true or the most important cause is.

VARIATIONS IN SPHERICAL REDUCTION FACTOR.

It is to be expected that the ratio of mean spherical to the mean horizontal candle-power of gas-filled lamps as now constructed should be subject to considerable variation inasmuch as it depends very largely upon the spread of the convolutions of the filament in the bulb. That is, a little difference in the shape

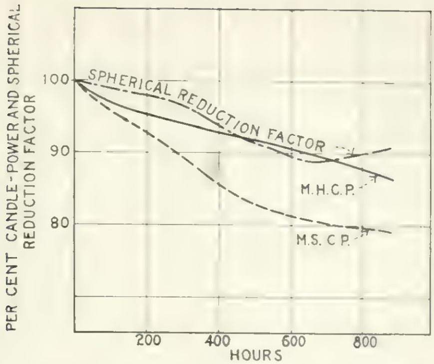


Fig. 4.—Variation of spherical reduction factor during life of a gas-filled multiple tungsten lamp.

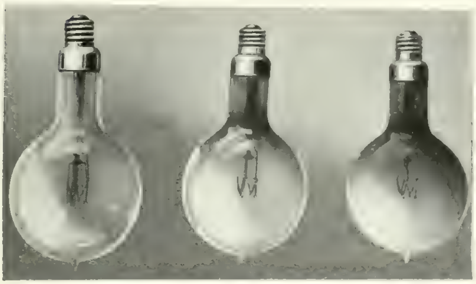


Fig. 5.—Blackened bulbs of gas-filled lamps.

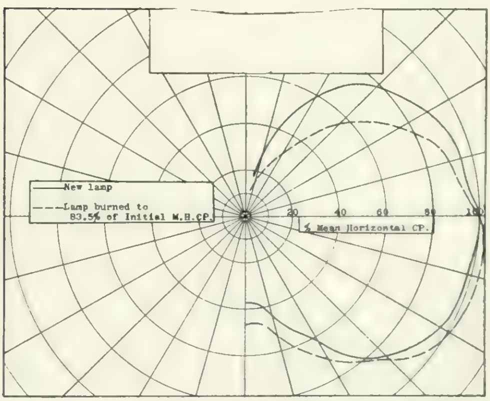


Fig. 6.—Mean vertical distribution of light from a 750-watt gas-filled multiple tungsten lamp.

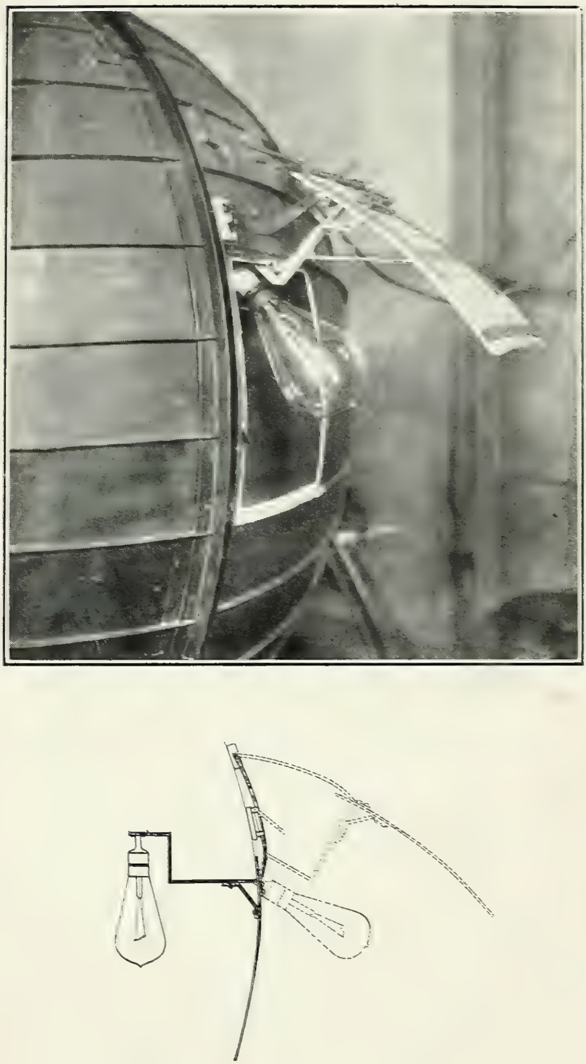


Fig. 7.—Quick handling device for integrating sphere.

of the wire supports by means of which the filament is held in its position may produce considerable variation in the spherical reduction factor. Therefore there is no constant spherical reduction factor applying to this type of lamp as there is to the ordinary type, and the mean horizontal candle-power is a very imperfect measure of total luminous output. Moreover the spherical reduction factor must vary during the life of the lamp. This is illustrated in Fig. 4. In the gas-filled lamp the volatilized tungsten is brought by the convection currents to the upper portions of the bulb, where it is deposited, as shown in Fig. 5. Therefore, the light in the upper heimsphere is diminished by absorption to a greater degree than that in the horizontal zone and in the lower hemisphere. This is illustrated in Fig. 6. The result of this is that the mean horizontal candle-power decreases less rapidly than the mean spherical and the reduction factor becomes smaller with the age of the lamp. However, because of the relatively small amount of light which passes through the zone where the tungsten deposit is made, this decrease is not so important as it otherwise might be.

Furthermore another effect which is due to the sagging of the filament may enter. At the high operating temperature, the filament is quite soft and some gradual change in its shape is to be expected. This change may either increase or decrease the reduction factor during the life of the lamp.

RATING OF GAS-FILLED LAMPS.

Thus it is clear that the time-honored practise of basing a lamp's total luminous output on measurements of mean horizontal candle-power, on the assumption of a fixed and known ratio between the mean horizontal and the mean spherical candle-power, is not applicable in the case of the gas-filled lamps. A similar condition arose with the tantalum lamps where the spherical reduction factor changed through the life because of a deposit of black on the equatorial zone of the bulb. In the engineering study of the performance of these lamps, this fact was taken cognizance of by coupling with the values of mean horizontal candle-power corresponding values of spherical reduction factor. This method was awkward, but it served the temporary purpose during the time when the tantalum lamp was in practical use. To

apply a similar method in the case of the gas-filled tungsten lamps, which bid fair to be a very important factor in the lighting situation, would involve entirely unnecessary trouble, and an equally unnecessary sacrifice of our scientific ideals. At the present time gas-filled lamps are rated on a system in conformity with the rating of other incandescent lamps. That is, the multiple burning lamps are rated in terms of watts, and their candle-power varies with the specific output of the lamp. The candle-power given is ordinarily expressed in terms of mean horizontal candle-power. In the case of previous types of incandescent lamps we have been getting along very well on this basis, but only because of the constancy of spherical reduction factors. As we have seen, we have in the gas-filled lamp a lamp in which the spherical reduction factor is no longer constant, and in which therefore the classic method of rating fails to be adequate. The time therefore would seem to be opportune for a change in the direction of a more scientific expression of the luminous output of these lamps at least. It is to be noted in this connection that these lamps come into the field of electrical engineering as competitors of arc lamps rather than as competitors of other incandescent lamps. It would seem therefore that the rating of the two types of illuminants could and should be made on equal bases. It is generally conceded that arc lamps should be rated on their total flux of light. On this account also the present rating of the gas-filled lamps is not the most useful or desirable one.

The introduction of these lamps then would seem to furnish an opportunity to adopt a logical basis of rating; namely, in lumens per watt, in the case of one type of incandescent lamp, with the hope that this method of rating may in the future extend to all classes of illuminants. The specific output of a lamp being expressed in lumens per watt, and the specific consumption in watts per lumen, the ultimate best interests of all would be served; those of illuminating engineers in that their illumination calculations would be made simpler, and of the lamp manufacturers in that they would find their testing and other engineering work facilitated. The disadvantages of making the proposed change would seem to be very small and temporary compared with the advantages to be realized.

Moreover, the difficulties in photometry which are indicated above, which arise from variation in candle-power due to rotation, would at once be done away with if the convenient and accurate integrating sphere method of photometering the lamps were to be adopted. The method by which large gas-filled lamps are handled in introducing them and removing them from a two-meter sphere in the Electrical Testing Laboratories is illustrated in Fig. 7. The method, simple as it is, is found to be fairly convenient and quick. In the case of smaller lamps at least, other methods may be used, making the measurements of the sphere quite as rapid and as convenient as measurements made on the ordinary bar photometer. Evidently, therefore, nothing from the measuring end lies in the way of rating of the lamps in terms of their total luminous output, and it is to be hoped that this important reform, for which our Committee on Nomenclature and Standards has expressed a pious wish, may in due course be realized.

DISCUSSION.

MR. PRESTON S. MILLAR: During the past two or three years lamp manufacturers have stated that they can manufacture vacuum tungsten lamps to specifications so accurately that for many purposes photometry may be dispensed with. This statement, however, does not apply to the gas-filled lamps. These cannot be manufactured to produce a uniform candle-power. In fact the variation in rating of individual lamps is greater than has been encountered in the vacuum types of lamps, even in the earlier periods of manufacture. Manufacturers are therefore forced to resume the photometry of individual gas-filled lamps, and in doing so, find themselves involved in the difficulties which Dr. Sharp's timely paper has described. As is pointed out in the paper, some of these difficulties are involved in the measurement of mean horizontal candle-power and disappear when the measurements are made with an integrating sphere, the basis being the total flux of light or the mean spherical candle-power. In view of the fact that the validity of the sphere method has been demonstrated, and that its practical utility in this class of work is no longer open to question, it is most gratifying to note

that difficulties inherent in the lamp characteristics are minimized when photometry is done with the aid of the integrating sphere.

An interesting question which has arisen in consequence of the changing spherical reduction factor of gas-filled lamps throughout life is the definition of "useful life." For years it has been customary to rate incandescent lamp life as the period of 20 per cent. candle-power decline, or the total life of the lamp if it fails before declining 20 per cent. This has been called the useful life. The mean horizontal candle-power has afforded a reasonably accurate indication of the decline in total light flux and has therefore been generally applied as a measure for determining useful life. The only exception was, as pointed out in the paper, the evaluation of tantalum lamps where recourse was had to the mean spherical candle-power. If now the gas-filled lamp life be evaluated on a basis of decline in mean horizontal candle-power, it will be found to be roughly twice the useful life arrived at through measurement of mean spherical candle-power. Precedent points to the mean horizontal candle-power as the measure for determining the rate of decline; engineering considerations point to the mean spherical candle-power. A disposition in this question will have to be made very shortly in order to prevent confusion.

Mr. G. M. J. Mackay: That the direction of convection currents in the gas is of some importance in gas-filled lamps is very strikingly shown to the naked eye in the case of a straight hairpin loop, say 8 or 10 centimeters long. When hanging vertically, the tip, for a centimeter or more on each side, is distinctly cooler than the middle of the filament, while the cooling effect of the leads, due to the hot currents of gas rising up the filament, is much less than for a similar filament in vacuum at the same temperature. If the filament be tipped to one side, so that one leg is vertical and the other sloping, the vertical wire is appreciably hotter than the other.

Mr. T. H. Amrine: I have made some study of the change in candle-power of gas-filled lamps with the speed of rotation and have come to the conclusion that this change is largely due to the breaking up or changing of the paths of the convection currents in the gas. The best evidence I have that this is so was

obtained from experiments upon a lamp which showed an increase of about 6 per cent. in candle-power and a decrease of about 1 per cent. in current when the speed of rotation was increased from zero to 165 revolutions per minute. This same lamp when exhausted of its gas and operated at the same temperature as before showed no appreciable change in current or candle-power with the speed of rotation. There are probably some changes due to bending of the coils, especially at high speed, but apparently it is largely a temperature change in the filament due to the alteration of the convection currents in the gas.

MR. J. B. TAYLOR: Dr. Sharp has presented interesting figures and curves of change in candle-power measurements of nitrogen-filled tungsten lamps resulting from rotation of the lamp.

Of the several possible explanations suggested, I am inclined to favor the theory of disturbed thermal circulation of the gas. If the normal circulation is arrested (and the centrifugal fan-action following rotation of the lamp would appear to do this) the gas closely surrounding the heated filament and therefore the filament itself will reach a higher temperature and hence give more light for the same voltage maintained at terminals.

Corroborative evidence that this is the state of affairs seems to exist in the increase of filament resistance when lamp is rotated, following along with increase of candle-power readings.

It should be possible to check the increased temperature and illumination from the measured resistance increase.

In those cases where reduced candle-power accompanies rotation, the centrifugal fan-action probably favors increased gas currents across the filament, which cool it.

MR. S. L. E. ROSE: Dr. Sharp has given us a very interesting paper and I can second his remarks in regard to the difficulties encountered in photometering large tungsten lamps. Bulb reflections sometimes make the distribution curves very irregular.

The total flux seems to be the logical basis upon which to rate these lamps; and for testing purposes this is already being done; that is, the lamps are operating at a definite total flux rather than at a definite horizontal candle-power. In comparing these lamps with arc lamps on the spherical basis, it must not be forgotten

that the arc lamp usually includes an equipment of globes and reflector which may materially reduce the total flux available from the arc. Therefore, before a fair comparison can be made between the two, it is necessary that either the incandescent lamp be equipped with a suitable fixture or the arc lamp be stripped of some of its equipment and a clear globe used.

SOME EXPERIMENTS WITH THE FERREE TEST FOR EYE FATIGUE.*

BY J. R. CRAVATH.

Synopsis: In the following paper are given the results of certain experiments with the method of testing for eye fatigue devised by Prof. C. E. Ferree. Some of the experiments were made under similar conditions of illumination, with the conditions of work and health variable, while other tests were made under varied conditions of illumination with the work and physical condition of the subjects as nearly as possible constant. The results seem to indicate that eye fatigue as measured by this method may be caused by abnormal work, general mental or physical fatigue, headache, and bad conditions of illumination. In the main the method of testing appears to give consistent results.

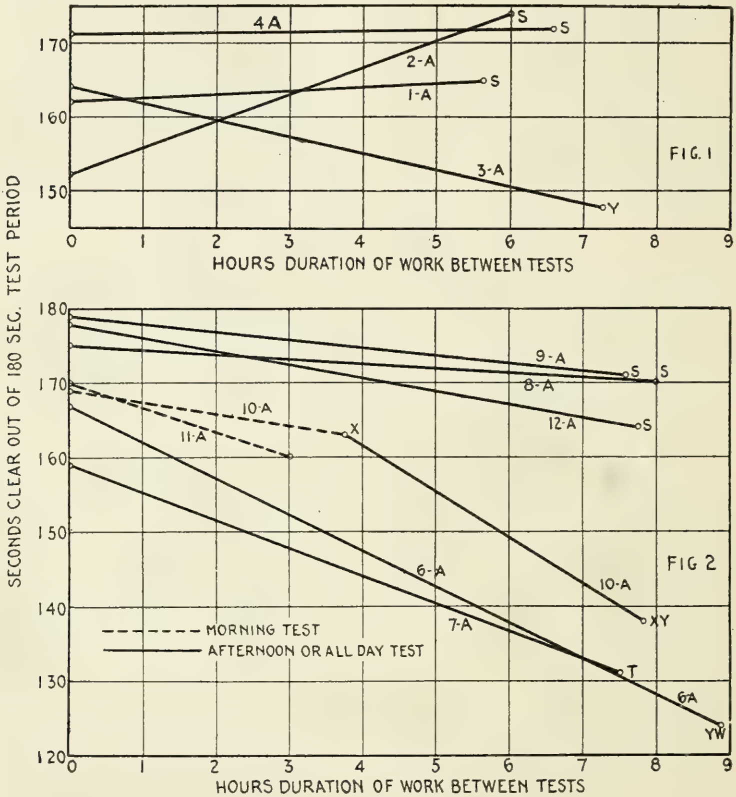
The object of this paper is to give the results of some experiments with the method of testing for eye fatigue devised by Professor C. E. Ferree of Bryn Mawr College and described in papers before the Illuminating Engineering Society conventions of 1912 and 1913.

The method of conducting the Ferree test is briefly as follows: The observer under test is required to gaze steadily for a short period of time (usually about three minutes) at a card upon which are printed certain letters, or characters; these letters being of such a size that they are just barely distinguishable at the distance selected for the test. During the period of time that the observer gazes at the letters he is required to record on a chronograph or stop watch by the pressing of a button the intervals when the test object appears blurred. The percentage of the time which the observer sees the letters blurred is taken as an indication or measure of the amount of fatigue of the eye at the time the test is made. Before beginning such a test it is of course important to determine the proper distance at which to place the test card from the eye of the particular observer under test because if too great a distance is taken the test letters may appear blurred during the entire test interval, in cases where

* A paper read at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., September 21-24, 1914.

there has been considerable eye fatigue; and on the other hand if too short a distance is taken the observer may see the test letters clear for the entire time during tests when the eyes are but little fatigued.

In the tests which I have made which are described in this paper a card with the letters li printed upon it was used; this



Figs. 1 and 2.

being the test object preferred by Prof. Ferree. Before any testing was done the observer who was to undergo the test for eye fatigue was first tested for the maximum distance at which he could distinguish the test card letters. Cards with the letters li and ll were prepared and it was determined for what maximum distance the observer could with certainty distinguish between

li and ll. The regular test distance for that observer was then taken as about one-fifth to one-sixth of the maximum distance.

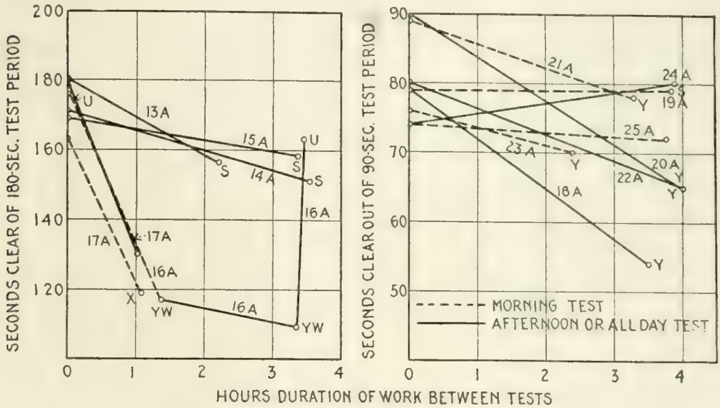


Fig. 3.

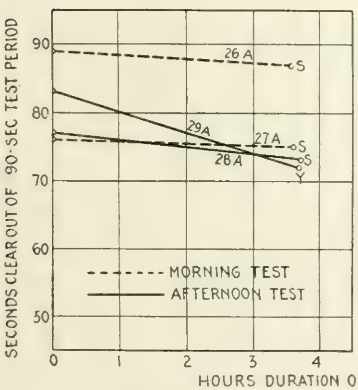


Fig. 4.

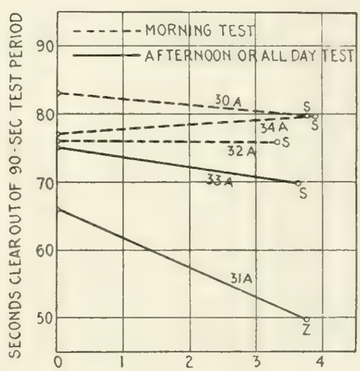


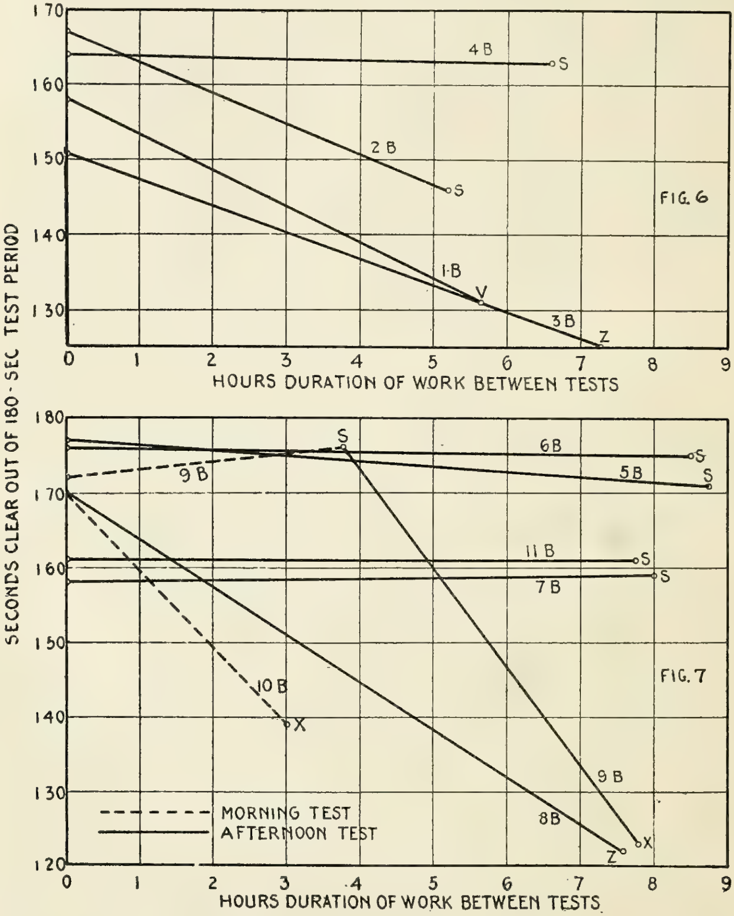
Fig. 5.

The observer under test is thus tested for eye fatigue before and after a period of work under the given conditions of illumination which are under investigation.

Many of the tests which I have made have necessarily been such as could be worked into the daily routine of a consulting engineer's office without too much interference with the productive work. They have been made with the object of determining

the behavior of the method under different conditions rather more than to test different methods or systems of illumination.

The usual impression of an observer beginning a series of these tests is that it is difficult to tell when the letters appear blurred and when clear. There is a feeling that there is considerable



Figs. 6 and 7.

guess work about the judgment made. This feeling never entirely disappears, but proof that it is not well founded is found in the fact that the results obtained from day to day under similar conditions correspond so closely to each other. In this

connection the reader should bear in mind that the curves in this paper are not plotted with the zero point on the scale shown, and that therefore the difference in the relative heights of the various curves is less than appears from casual inspection.

A preliminary set of tests were made on various persons in my office during 1913. These were made before and after work under ordinary variable office daylight conditions. The test card was illuminated by daylight during these tests. These tests gave sufficiently consistent results so that this year, 1914, more systematic work was attempted. Figs. 1 to 8 inclusive give the graphic results of these 1914 tests.

Each test has a number and the letter following this number designates the observer. Thus, 1A designates the first test made

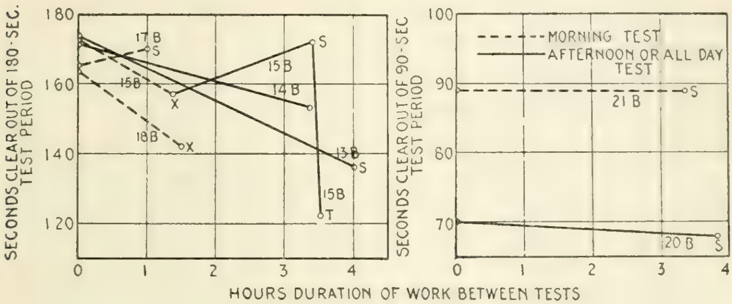


Fig. 8.

on observer A; 2B the second test on observer B and so on. The letters from S to Z marked after some of the tests refer to a key given later, which gives some of the peculiar conditions influencing the tests.

The general plan was to test each observer in the morning when the eyes were presumably fresh and before any work was done and then after a number of hours work. It will be noted that many of the working periods between tests cover from six to nine hours. During the earlier work the first test was made in the morning and the second test was made the latter part of the afternoon with the usual lunch hour intervening. It was later found that there is a marked recuperation during the lunch hour, especially where the work before lunch has been very try-

ing. For this reason all of the latter tests were made separately before and after both afternoon and morning periods. A careful journal was kept of conditions of work and illumination for each test and any members desiring more information than is given in this paper are welcome to inspect these records. Mention will be made here only of some of the more important points.

KEY TO FIGURES 1 TO 8, AND 10 TO 14.

Arabic numerals indicate number of tests.

A, observer A.
B, observer B.
E, observer E.
S, good daylight and no abnormal work or other known disturbing conditions.
T, low results due to a similar fatigue test made a short time before.
U, recuperation by exercise and relaxation from work.
V, eyes irritated other than by work.
W, general fatigue and need of relaxation.
X, results believed to be due to defective illumination.
Y, abnormally difficult or long continued hard eye work.
Z, headache not caused by eye strain.

Most of the tests in Figs. 1 to 8, except where specially noted later, were made before and after working under excellent daylight conditions or with indirect lighting mixed with daylight. The light came from large windows at one side of or behind the workers. Considerable sky area and white enameled brick work were the sources of illumination. On very cloudy days indirect lighting from large ceiling areas supplemented the daylight.

Tests 1A to 4A, Fig. 1, and 1B to 4B, Fig. 6, were made with the test card illuminated by daylight. Daylight being an exceedingly variable quantity especially in the winter in Chicago's down town district all following tests were run under fixed conditions of test card illumination. Except in the case of the tests made in a special illumination test room later described, all of the three-minute tests following 4A and 4B were made in a room from which daylight was excluded and with the test card illuminated so as to give a constant brightness of about 0.0166 candle-

power per square inch. Those made in the illumination test room were also under fixed illumination conditions given later.

As only a few of the tests in Figs. 1 to 8 were made under what might be considered adverse illumination conditions, special mention will be made of a few that were made under such conditions. Such tests are designated by the letter X on the curves. Test number 10A, Fig. 2, followed a period of work shorthand writing in a small room with a 100-watt clear tungsten lamp in an opaque mirrored reflector 7 ft. 10 in. (2.39 m.) from the floor, over the desk, 14 in. (35.5cm.) in front, and 14 in. to the left of a point directly over the book. The lighting was entirely artificial, being secured by pulling down the window shade on a very cloudy day and inverting the indirect lighting fixture. Considerable glare was received from the paper and the desk top.

Tests 10B, Fig. 7, and 18B, Fig. 8, were made before and after periods of work looking over typewritten manuscripts, etc., with no natural light and all of the artificial light coming from a 100-watt clear tungsten lamp in an opaque mirrored reflector hung over the desk 7 ft. 10 in. (2.39 m.) from the floor, 25 in. (0.5 m.) in front and 14 in. (35.5 cm.) to the right of a point directly over the observer's paper. Glare from the paper and from the antique finished oak desk top was annoying, but probably would not have been recognized as the cause of trouble by the layman. It was, however, decidedly noticed and objected to by observer B. The effect on that observer was a slight nausea similar to that experienced by him when attempting to do too much reading on a long railroad journey over a rough road.

A study of tests 1A to 19A and 1B to 19B indicates that the test is quite sensitive to conditions such as unusually difficult or long continued eye work, general bodily fatigue, and headache, as well as to adverse illumination conditions. This is what might be expected if the method of test is one which is of value for testing differences in fatigue of the eye due to differences of illumination. In other words, if the test is sufficiently sensitive to bring out differences in eye fatigue caused by illumination it should also be sensitive to other conditions which adversely affect the eye. The recuperation by means of exercise just before making a test is somewhat striking in some cases.

Tests number 17A, Fig. 3, and 15B, Fig. 8, were made in the illumination test room described later with the observer reading and facing bowl frosted tungsten lamps at the ceiling equipped with etched prismatic reflectors.

Tests numbered 3E to 31E, Figs. 10 to 14 inclusive, were made in the attempt to determine the relative eye fatigue upon a bookkeeper working continuously under different given conditions of artificial illumination. In co-operation with the Commonwealth Edison Co. of Chicago, a room was set aside in a modern office building for the purposes of this test. A plan of this room is given in Fig. 9. An experienced bookkeeper (observer E) from

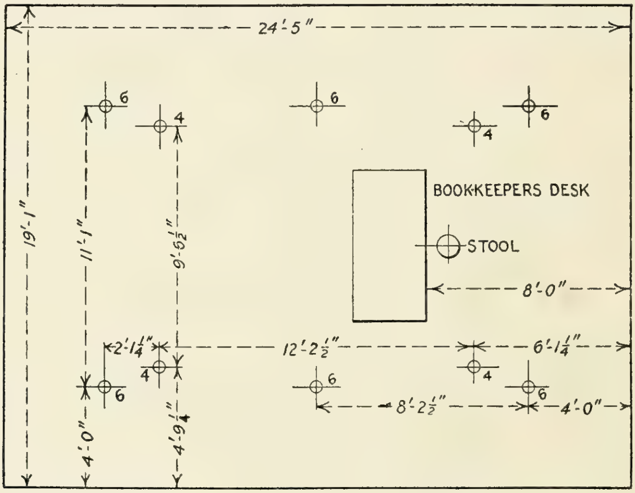


Fig. 9.

the accounting department of that company was assigned to work steadily in this test room for a period of five weeks. Five different typical modern illumination equipments were tested, one week being devoted to each. The bookkeeper, observer E, was tested before beginning work in the morning, before noon lunch hour, just after the noon lunch hour, and after the close of business each evening. This observer did the regular work on the company's books on a regular bookkeeper's desk located as shown in the plan, Fig. 9. Before this set of tests was begun this observer went through five preliminary tests to accustom himself to the

methods. When the observer was looking at the test card the card was placed at one end of the bookkeeper's desk and the observer was seated at the opposite end of the desk with his chin rested against the desk. This series of tests were all made with a test card brightness of about 0.00354 candle-power per square inch. This corresponds to about 2.1 foot-candles.

The room, Fig. 9, was 10.5 ft. (3.20 m.) high. All daylight was excluded. The ceiling was a very light cream nearly white and the walls were light yellow.

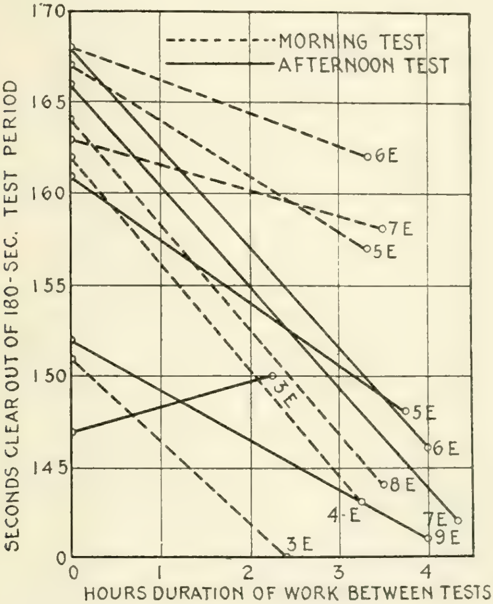


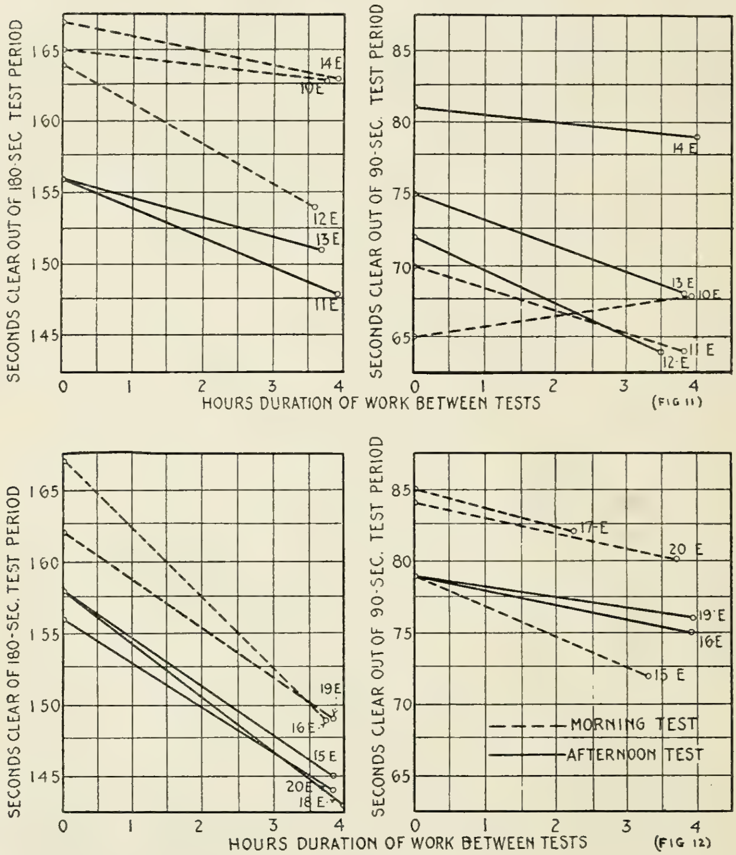
Fig. 10.

In tests numbered 3E to 9E, Fig. 10, lamps were placed at the six outlets numbered 6 on Fig. 9. These lamps were at the ceiling and were bowl frosted tungsten lamps in etched prismatic reflectors[1] of the intensive type. At the four corner outlets 100-watt lamps were used while those on the center line of the room were 60-watt lamps.

The illumination on the bookkeeper's desk was about 4.25 foot-candles and this illumination was kept constant during all of

[1] Holophane silver finish.

this series of tests with the different systems of lighting. The results of the first week test covering this system are shown in Fig. 10. It is to be noted that these results are somewhat more erratic than the results obtained the following weeks after the observer had become more accustomed to the test. With this



Figs. 11 and 12.

installation the brightest surfaces within the field of vision of the observer were the frosted bowls of four lamps which were probably about 6 candle-power per square inch.

The next system tested, Fig. 11, tests 10E to 14E inclusive, is commonly known as a semi-indirect system. At each of the

outlets marked 4, Fig. 9, an inverted art glass[2] bowl was suspended. The brightest surface within the field of view was the bowl, 0.3452 candle-power per square inch.

Beginning with the test of this system and continuing through the remainder of the tests in this room a modification of the Ferree method was tried for half of the tests. This modification was devised by the writer upon the theory that the fatigue of the eye brought on by working under bad illumination might be largely muscular fatigue of the iris caused by its effort to adjust for widely varying brightness within the field of view. The Ferree test is essentially a test of the ability of the observer to hold all of the muscles of the eye steadily fixed in one position for a period of three minutes. It was thought by the writer that perhaps a method of test which would put more active work upon the iris muscle and the nerve centers controlling it might bring out more prominently eye fatigue due to bad illumination conditions. It is well known in some cases of bad illumination that excessive work is put upon the iris by frequent necessity for contraction and expansion to adjust for the decided differences in brightness within the field of view.

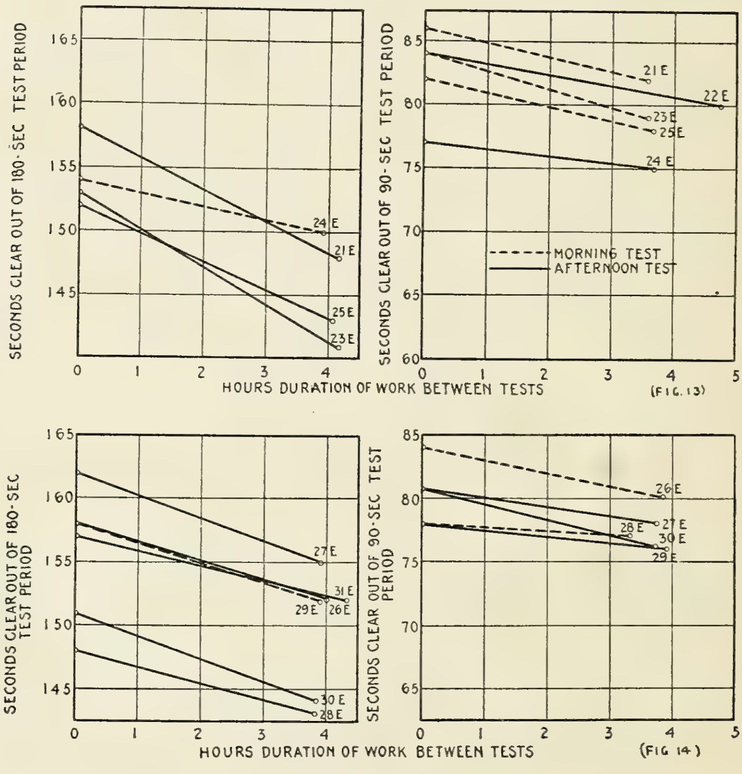
The modification of the Ferree method devised by the writer and tried here was to vary the quantity of illumination on the test card and within the field of view during the period the observer is gazing at the card. It was found that varying the illumination on the card 17 per cent. by the switching on and off of one of the lamps in the room would cause a very appreciable expansion and contraction of the iris in response without at the same time varying the illumination enough to cause annoyance to the observer in distinguishing the test letters. However, the test was so much more severe on the eyes that it was necessary (or at least believed to be necessary) that the test period be shortened to 1.5 minutes instead of 3 minutes as with the regular Ferree test. In Figs. 11 to 16 the regular Ferree 3-minute tests are given at the left and the modified 1.5-minute tests are given at the right.

In Fig. 12 are given the results of a test on another typical modern direct lighting installation similar to the previous direct

[2] Monolux.

lighting installation except that a very dense opal reflector[3] was substituted for the etched finished prismatic reflector.

In Fig. 13 are given the results of similar tests with purely indirect lighting fixtures at the four outlets marked 4 on Fig. 9. In this case the brightest surface within the field of view of the observer was the ceiling above each fixture which as viewed by



Figs. 13 and 14

observer E had a brightness of 0.0536 candle-power per square inch.

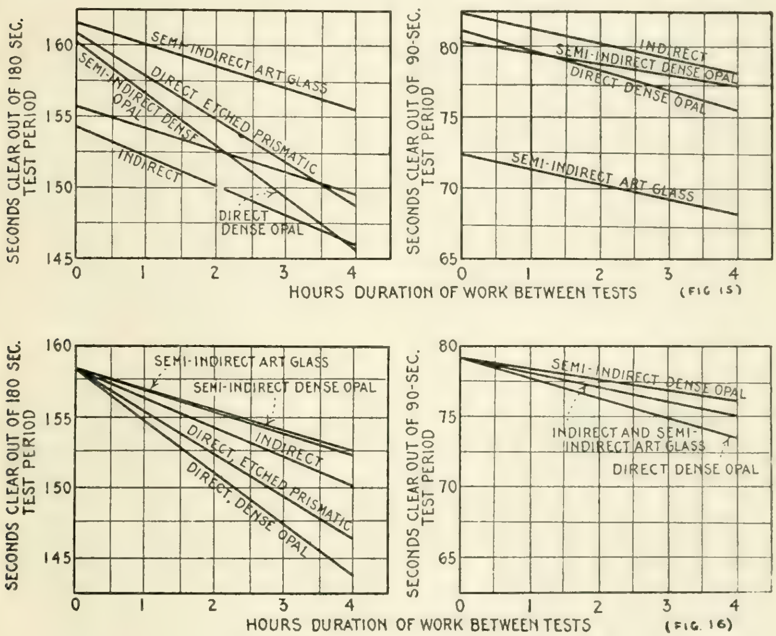
Fig. 14 shows the results of similar tests on a system which would commonly be classed as semi-indirect but which in reality has a very small direct component. Four semi-indirect, dense opal bowls[4] were hung at the outlets marked 4. These are of a

[3] Sudan.

[4] Calla.

very dense opal glass and the surface brightness of the bowl is only about 50 per cent. greater than the brightness of the ceiling above the fixture as viewed by the ordinary observer. The ceiling and bowl brightness was not measured in this case, but from tests made on other installations the relative brightness of bowl and ceiling for this installation was approximately obtained.

To summarize and average these results upon observer E in the illumination test room the angle of slope was averaged from the



Figs. 15 and 16.

plotted tests of each installation and the average results are given in Fig. 15. In order to reduce these to a shape easier of comparison, Fig. 16 was prepared in which the starting point of all the curves is arbitrarily taken as the same.

It will be seen that the modified Ferree test as carried out in this case apparently did not give as positive results as the unmodified test. Moreover the modified and unmodified tests do not always agree in their general conclusions, except that they put the systems with the brightest surfaces within the field of view

at the bottom of the list for desirability. It is probable that the method as carried out with the limited number of tests on each installation and with the possible variations in the physical condition of the observer was not sufficiently sensitive to bring out the differences between the indirect and semi-indirect systems tried. An inspection of the daily journal of the tests shows some conditions likely to affect the observer adversely for the work of the indirect test. In Fig. 17 is given an attempt to average all

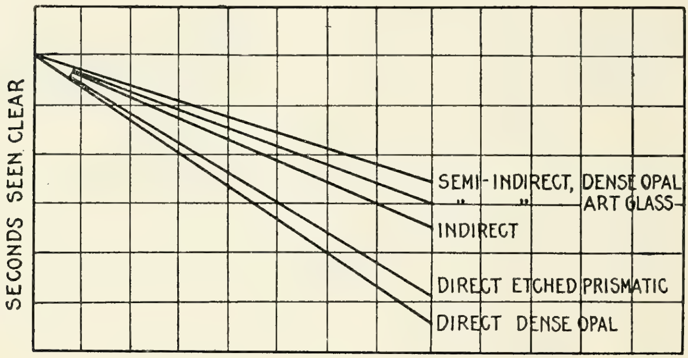


Fig. 17.

the tests on observer E in the illumination test room by reducing the modified and unmodified tests to a common basis. This was done by finding the average difference of slope between the modified and unmodified tests, increasing the slope of the modified test by this ratio, and then averaging the modified and unmodified tests. This is believed to be as fair a method as could be devised.

Brightness of Surfaces within the Range of Vision, Observer E.—The following figures are of interest in connection with the tests on observer E in the illumination test room.

System	Brightest surface within range of vision candle-power per sq. in.
Indirect	0.0536
Very dense semi-indirect (estimated)	0.0750
Art glass semi-indirect	0.345
Direct dense opal reflector and bowl-frosted tungsten lamp	6.00
Direct etched finished prismatic and bowl-frosted tungsten lamp	6.00

The ratio between the brightness of the ceiling with the indirect system and the brightness of a piece of blotting paper on the bookkeeper's desk was as 1 to 7.1 while the brightness of the bowl frosted tungsten lamp with either of the direct systems as compared to the brightness of a piece of blotting paper on the bookkeeper's desk was as 1 to 800. Wall brightness measurements were taken with the various systems, but did not show enough variation to justify publication here.

The results obtained from the various tests recorded in this paper indicate that the Ferree method is reasonably sensitive both to eye fatigue caused by illumination and to eye fatigue due to other conditions such as abnormal eye strain, headaches, unusually difficult eye work and irritation due to dust in the eyes. If it is used as a test of illumination conditions care should be taken to eliminate as far as possible the other variables and to throw out tests where these variables influence the result.

The writer now believes that a mistake was made in not adopting longer card reading distances in all of these tests as more pronounced results would probably have been obtained by so doing.

In the modified Ferree test described the test period should have been made longer than 1.5 minutes, but even at that it is doubtful whether the method would do better than simply to equal the sensitivity of the unmodified method.

DISCUSSION.

THE CHAIRMAN (Mr. C. O. Bond): This is the kind of a paper I like, gentlemen. We need a criterion as to the desirability of schemes of lighting. Dr. Ferree came forward and in work extending over two years has tried his best to give one to us. His suggested method has been taken up in good faith by one of our members to be tried out. Others of us should follow suit. It is an attempted criterion and we owe it to the authors who have worked hard to develop its method to give it a fair trial. If we do not look for the truth and, when we find it, hold it up to view, we are derelict in our duty to science. This paper is now open for discussion.

MR. E. B. ROWE: One thing that interested me is the ap-

parent variation between Mr. Cravath's and Dr. Ferree's results, in the relative fatigue under the different methods of illumination. Also, personally, I wish clear prismatic reflectors had been tested as well as the satin finish. I believe there is not the marked difference between these, or between clear prismatic and opal reflectors, that is sometimes said to exist.

MR. W. A. DURGIN: It cannot be too strongly emphasized, perhaps, that the deepest impression made by first observations under the Ferree method is that of extreme indefiniteness in distinguishing between clear and blurred seeing. As the observer goes on, however, he finds that the precision of his results is much better than he expected and he has the tendency to swing to another extreme and assume that fair precision means direct measure of eye fatigue. To me, it seems particularly significant that the final rating of systems derived from Mr. Cravath's tests of the bookkeeper's eyes is in accordance with this bookkeeper's preconceptions and prejudices as disclosed in personal conversations which I had with him, a consideration which gains weight from the fact that the bookkeeper was especially anxious to keep his results free from personal bias.

At first thought this may seem an adverse criticism of the method, but in reality I believe the apparent defect of the test constitutes its greatest excellence, for prejudice is a large and always present factor in the seeing of everyone excepting possibly the lighting specialist.

The man who from childhood associations is always exhilarated by the sparkle of the ocean may experience sufficient invigoration from the scintillation, characteristic of lighting with direct units, to entirely neutralize the effects of resultant glare, while one whose formative years have been passed in a foggy climate may find generally diffused light the necessary condition for best seeing. These idiosyncrasies will generally be quite unconscious—these will be true prejudices; but will be of fundamental importance in determining the best lighting arrangements for the individual.

A method such as that developed by Dr. Ferree which probably displays the combined result of the ocular peculiarities, physical state, and conscious or unconscious prejudices of the

subject tested gives great promise as a reliable indicator of the best system for any particular user or small group of users. If the method when applied to large numbers of people shows no marked universal superiority for any system yet devised, it will have demonstrated thereby, perhaps, its close approximation to fundamental truth.

MR. G. H. STICKNEY: We are certainly in need of information as to what is best and most effective in lighting, and how other values besides those of intensity can be reliably determined. We are greatly indebted to authors such as Dr. Ferree and Mr. Cravath, who have favored us with the results of their extensive investigations. They have evaluated lighting systems in terms of eye fatigue. There is a question in my mind as to just how far we can rely on fatigue in determining the true useful value of illumination. Probably it is a right basis, but I am not sure that it is proved.

In talking with a watch maker, who was working with a magnifying glass at his right eye, I asked him if the severe use did not tire that eye. He replied that it was sometimes rather tired at night, but that on account of the continued use it was stronger and better than the left eye.

Now we know that with regard to our muscles that a certain amount of fatigue-producing exercise is beneficial, rather than otherwise. Of course, excessive strain is injurious. From this point of view the interpretation of fatigue as a measure of illumination seems rather complicated. The author has undoubtedly given much thought to this question, and perhaps he can explain it more clearly to me.

MR. F. C. CALDWELL: This question of eye fatigue, from a quantitative, as distinguished from a qualitative point of view, is one of the vital problems that we have before us. We have been doing a little work along this line at the Ohio State University, but are not altogether satisfied with our use of Dr. Ferree's methods, and so we have nothing very definite to publish. The line that we tried to follow dealt with the fatigue from different systems under varying degrees of illumination. The results seem to indicate that from one to three foot-candles there is very little difference between the direct and the indirect systems, where the

direct system is represented by bowl-frosted lamps with high grade reflectors. Above three foot-candles the curve giving the fatigue with the direct system rises quite rapidly; whereas, with the indirect system it remains nearly horizontal, indicating that for illumination intensities in the neighborhood of seven or eight, the fatigue with the direct is several times as great as with the indirect.

DR. C. E. FERREE (Communicated): I have been very glad to have Mr. Cravath take up work with the test for loss of efficiency of the eye as the result of a period of work under different conditions of lighting. His tests seem to have been very successfully conducted and I appreciate his co-operation in the attempt to find out what are the possibilities and characteristics of the test. However, since the object of his work, like ours, has been primarily a study of the test rather than an ultimate investigation of lighting conditions, it may not be out of place to note here some points of difference between our work (1) in the way the tests have been conducted, (2) in the way the results have been evaluated and represented, and (3) in the way in which the tests have been applied to different lighting conditions for the purpose of comparing the results obtained.

(1) It is probable that Mr. Cravath has rendered his tests unnecessarily insensitive by using too high a ratio of time clear to time blurred, *i. e.,* he has worked too often with the test object too near the eye. For example, he has frequently used a working distance of observer for test object which gave him 168 sec. clear and 12 sec. blurred. We have found that the greatest sensitivity is not gotten with more than 130-140 sec. clear, or a ratio of time clear to time blurred of 3.5. The distance required to give approximately this ratio much of course be determined in preliminary tests for each observer, and should be kept as nearly constant as possible for that observer in every case in which it is wanted to compare the results of the test. We do not find that sensitivity is added to the test by putting the eyes under greater strain or by working with the test object further from the eyes of the observer. Probably it would not be out of place also to emphasize the importance of the kind of recording apparatus and the rigidity with which the observer's head

is held in position while the test is being made. The recording apparatus should be such that no time is lost in recording the judgment and that fractions of seconds may be taken account of in computing the score. For example, a total of no more than a half second added to the time clear and subtracted from the time blurred makes a difference in 0.35 in the ratio time clear to time blurred when a working distance is used which gives 168 sec. as the total time seen clear. Also a better head rest than was employed by Mr. Cravath should, I think, be used. Two reasons may be assigned for the employment of a proper head support. (1) It is necessary that the distance of the eye from the test object be accurately the same at the close of work as it was for the test at the beginning of work. It seems improbable that constancy in this distance can be secured unless some fixed system be employed which includes a graduated track to carry the test object and a rigid support for the head. It can scarcely have been secured, I think, even for the small period of time consumed by the test by resting the chin against the edge of the table as was done in Mr. Cravath's experiments. Any change in this fixed relation of eye to test changes the ratio of time clear to time blurred. Moreover, (2) any movement of the head invariably results in compensating eye-movements which break up the strain imposed by the test upon the muscles which hold the eye adjusted for its work.

(2) Mr. Cravath has not used the same method of evaluating and representing his results as was used by us. For example, he has represented loss of efficiency by the difference in number of seconds in which the test object was seen clear in 180 sec. before and after work. Nor does he seem to be entirely clear with regard to our method of scoring loss of efficiency. In describing our method, he says: "The percentage of the time which the observer sees the letters blurred is taken as an indication or measure of the amount of fatigue of the eye at the time the test is made." This seems to imply that the percentage of time blurred to the total time of the observation was understood by him to be our method of representing loss of efficiency. This is not the case. We took as our representation of loss of efficiency for clear seeing at the time the test was made, the ratio of the

time seen clear to the time seen blurred. Mr. Cravath plots for himself only the time seen clear. His method of plotting the results does not directly take into account the time seen as blurred, nor does it permit of a direct comparison of results from an inspection of the slope of the line drawn between the points representing the times at which the two tests were taken. For example, 140 sec. seen clear at the beginning of work and 130 sec. seen clear at the close of work would give the same slope of line as 130 sec. seen clear at the beginning of work and 120 sec. at the close. That is, the difference in each case would be 10 units of the scale he has used. Evaluated by the method we have employed, however, the difference in the number would not be the same. In the former case, for example, the difference between the ratios time seen clear to time seen blurred before and after work would be 0.9, and in the second case 0.6. By Mr. Cravath's method of plotting results, the slope of the line obviously can not be taken as directly representing loss of efficiency. The slope of the line and the zero point of the scale must both be taken into account. In other words a ratio is also implied in his method of plotting, namely, a ratio of the time seen clear to the total time of the observation. This ratio, however, is not expressed in the slope of the line nor is it readily discoverable for purposes of comparison on casual inspection of his charts. We have used a different ratio, namely the ratio of the time seen clear to the time seen blurred, and have represented this ratio directly in the slope of our line for purposes of comparison. Either method may be used. But with reference to the present paper, two points must be borne in mind. (1) Loss of efficiency is not represented by the slope of the line in Mr. Cravath's charts; and (2) in attempting to make any proper comparison, however rough, between his results and ours, the difference in the method of representing the results must be taken into account. In order that there may be some proper basis of comparison of the results obtained by both of us, we have evaluated some of Mr. Cravath's results by the method we have used. That is, we have compiled tables expressing these results in terms of difference in the ratio time clear to time blurred before and after work, and have plotted curves in which this difference is shown directly by the slope of the line.

TABLE IVa.

Showing the average of the results obtained by Mr. Cravath for loss of efficiency as the result of a period of work expressed in terms of the ratio time clear to time blurred.

Lighting system	Total time clear	Total time blurred	Ratio total time clear / total time blurred	Ratios reduced to common standard
Semi-indirect, dense opal...	156	24	6.5	3.5
	149	31	4.8	2.58
Semi-indirect, art glass.....	162	18	9.0	3.5
	156	24	6.5	2.53
Indirect	154	26	5.9	3.5
	146	34	4.29	2.53
Direct, etched prismatic.....	161	19	8.47	3.5
	148	32	4.6	1.9
Direct, dense opal..........	160	20	8.0	3.5
	146	34	4.29	1.88

(3) In comparing Mr. Cravath's results for the different systems of lighting employed the following points should be taken into account. (1) His units for the different systems were not in the same place in the field of vision. They were in the same place for the semi-indirect and the indirect systems, but were quite a little removed from this position in case of the direct system. At present we are not prepared to say just how much importance should be attributed to the position of a bright surface in the field of view in considering the effect on the eye's loss of efficiency. We have begun an investigation of this point but are not as yet prepared to give conclusions. We have found, however, that the position of the brilliant surface in the field of view is a very important factor in the tendency to produce discomfort. (2) His comparisons were not made for the same number of lighting units in the field of view for the three systems. Four units were in the field of view for the direct system, and only two for the semi-indirect and indirect systems. So far as the indirect system is concerned this difference would probably be of no consequence, for our results with the same reflector show that the effect on the eyes is, within the limits under consideration, independent of the number of units in the field of view. This conclusion would doubtless apply also to the denser semi-indirect

reflectors because of their low surface brightness. In comparing the results for the art glass semi-indirect[a] reflectors, however, with those for the direct system, the difference in the number of units in the field of view should perhaps be taken into consideration. But even in this case the probability of a difference in effect due to a difference in the number of units in the field of vision is much lessened by the fact that two of the four units used were close to the edge of the field of vision. (3) His period of work was not uniform for the different systems. With regard to the length of the working period, the direct and semi-indirect systems were favored, the direct system the most. That is, for the direct system the average period was quite a little less than 4 hr.; it was a little less than 4 hr. for the semi-indirect system; and quite a little more than 4 hr. for the indirect system. For example, in case of the work for the unmodified test, of the four tests given for the indirect system, three lasted over 4 hr. and one a trifle less than 4 hr. Of the six tests given for the semi-indirect opal, one lasted a little more than 4 hr., one lasted 4 hr., and four less than 4 hr. Of the five tests given for the semi-indirect art glass, three lasted about 3½ hrs., and two a little less than 4 hr. Of the five tests for the direct opal, one lasted 4 hr., and four less than 4 hr. And of the ten tests for the direct prismatic, one lasted a little more than 4 hr., two lasted 4 hr., five lasted about 3½ hr., and two lasted a little over 2 hr. For the unmodified test, similar inequalities obtained. With regard to the length of the working period the direct systems, it will be noted, were especially favored, more particularly the prismatic reflectors. It is scarcely necessary to call to mind that our own work shows that the length of the working period is quite an important factor in the results obtained. An inspection of the chart for the prismatic reflectors given in Fig. 10 of Mr. Cravath's paper also reveals that one of the results averaged into the final curve plotted for a comparison of the systems shows a considerable rise in efficiency as the result of work. This result is so conspicuously different from the other nine shown in this chart, and so probably due to some uncontrolled factor extraneous to the conditions being tested that it is very questionable whether it

a—Monolux.

should have been included in the average made for the purpose of comparison.[1]

This test was conducted, moreover, only for a little more than 2 hr., and its results, showing a rise rather than a loss in efficiency, when averaged in with the others, all showing a loss, have, it may be seen, quite a little effect on the slope of the final curve shown in Fig. 15.

The question of the reproducibility of the results given by the tests has been raised by Mr. Cravath and others at this session. The test, it must be clearly recognized from the outset, falls in the class of subjective tests, and must be treated accordingly. That is, the characteristics of the eye, the measuring instrument, and the factors which influence it in its relation to the given task, should be studied and controlled; and in addition a careful determination should be made of the mean variation and of how this mean variation compares in each case with the experimental variation. Our first attempt at a safeguard against factors which might have escaped the work of standardization was to get some objective check on the judgment of clear and blurred; for example, the letter i might at times be made to appear to the right of the letter l, and again to the left, or other kinds of test object could be used which offer greater possibilities of variation; and a record could be kept of these variations to correlate with the subjective record or judgment that is made of them. This, however, would require that the test object be changed; and each change in the object, however, skilfully made, would cause a readjustment of the eye which in turn would tend to relieve the steady strain on the muscles of the eye which is the prime feature needed to give sensitivity to the test. After some six months of futile attempt in this direction, we turned our attention instead to the careful determination of the mean variation of the results of the test when properly standardized. We found this mean variation to be much smaller than we had supposed. One of our ways of obtaining the order of magnitude of variation of the test for the fresh eye was as follows. Beginning at 9 A. M. five 3-min. tests were run with a rest interval of 20 min. between each test.

[1] This result is, for example, very similar to the result obtained by us when adaptation of the eye to the degree of illumination used had not been properly standardized.

This was done with all observers on several days under each system of lighting employed. The rest interval was taken in each case in a room lighted by daylight with the observer facing a wall with an evenly lighted mat surface. For a single series of five tests the variations in the time clear in the 3-min. periods have always fallen within 1 per cent. for all the observers we have used for all systems of lighting, and within ½ of 1 per cent. for our most experienced observers. This, it will be seen, is very small indeed as compared with the variations in the results produced by the different conditions of lighting used either by Mr. Cravath or by us. The method used is a subjective method, it is true; but so are the methods used in photometry and in many other departments of the work of the lighting engineer. Moreover, because of the nature of the problems it is designed to solve, it has to be subjective. It would, in fact, be of little use if it were not subjective. All that we can hope to do, therefore, is to make it as sensitive as possible and to get such control of the factors to which it responds as to give the results obtained the desired degree of reproducibility with a given set of conditions to be tested. This, I think, we have already succeeded in doing with a fair degree of success.

A question has also been raised here with regard to the closeness of agreement of Mr. Cravath's results with ours. When one considers the number of points of difference in the conditions surrounding the two pieces of work, the amount of agreement seems to be all that could be expected. The following points of difference in conditions may be noted. (1) The tests were not given in the same way and different methods were used in recording and evaluating the results. (2) With one exception different reflectors were used in the two pieces of work to give the three types of lighting employed. (3) The units were not in the same place in the field of vision. (4) In Mr. Cravath's experiments 4 units were in the field of view for the direct systems and only 2 for the indirect and semi-indirect systems. His curves, therefore, for these systems, if compared at all with ours, should be compared only with those for the same number of light sources in the field of vision. All comparisons, too, should be based on illumination effects rather than on class or type of

system.[2] (5) A different kind of work was used than was employed in our tests, also a different length of working period. On the average he used a 4-hr. period while we used a 3-hr. period. (6) His tests were made both in the morning and the afternoon on successive days in the regular routine of office work. Ours were made always from 9 to 12 in the morning, and especial care was taken that no tests were given when the observer was not in normal physical or optical condition.[3]

An important feature of Mr. Cravath's paper from the standpoint of the reader is his presentation of data showing the influence of certain factors on the results of the test. Although we have recognized the contributive value of such data, so far we have not felt justified in taking the time systematically to compile them for publication. Early in the work, as a necessary preliminary step to the employment of the test for any kind of work, we conducted investigations to find out what are the factors that influence the test, and used the results of these investigations as a guide in establishing our standard conditions. The work of the first year was in fact pretty largely taken up with this type of study and preliminary standardization. Moreover, it still continues, and doubtless will continue as long as the application of the test to new fields brings to light new points of sensitivity. A very important factor, for example, was brought to light this year which has not been noted by Mr. Cravath and which in all probability will not be noted by him as long as he works within

[2] We regret that Mr. Cravath has not published a fuller specification of illumination effects. He has given us only the amount of light falling on the bookkeeper's desk and the brightness values for the test surface and the brightest surfaces in the field of view. With regard to the brightest surface in the field of view, for the two sets of experiments the following approximations occur which afford perhaps some basis of comparison. The brightest surface in the field of view for his indirect system was 0.0536 cp. per sq. in.; for our indirect reflectors for the 40-watt lamps with socket extenders it was 0.0539 cp. per sq. in. The brightest surface for his dense (Calla) semi-indirect reflector was 0.075 cp. per sq. in.; for our indirect reflectors for the 60-watt lamps it was 0.0704 cp. per sq. in. For his less opaque (Monolux) semi-indirect reflector, the brightest surface was 0.345 cp. per sq. in.; for our alba semi-indirect reflectors for the 60-watt lamps it was 0.370 cp. per sq. in. With the maximum brightness for his direct systems, 6 cp. per sq. in. we have nothing to compare.

[3] No statement is given by Mr. Cravath either of the age of his observer, nor is a clinic report given of the condition of his eyes. Further, a comparison of results is scarcely possible in the two cases unless a more detailed specification be given of the illumination effects present in Mr. Cravath's experiments. We are prompted to this discussion only because we wish to emphasize the difficulty of fairly comparing results when they are not obtained under conditions closely identical.

a small range of intensity of illumination, namely, the influence of the state of adaptation of the eye at the beginning and the close of work. If, for example, the illumination of the test room is lower than what the eye has experienced for some minutes prior to the beginning of work, a low visual acuity will result. This will mean the selection of a working distance for the test too close to the eye. That is, as the eye becomes accustomed or adapted to the new illumination, it will increase in sensitivity and the ratio of the working distance to the maximum acuity distance will get smaller, and the ratio of time clear to time blurred will get larger. The result of this of course is to mask the actual loss of efficiency as the result of work. In case of a favorable lighting system it in fact causes an apparent increase in the efficiency of the eye as the result of a period of work, instead of a loss. In the early part of our work with the indirect system for the lower intensities of light, this apparent increase as the result of a period of work always occurred. It was found necessary, therefore, to allow a period of adaptation, without work, to the illumination of the room before the first test was taken. To determine the length of time needed under a given intensity of light to insure a constant acuity of vision so far as adaptation is concerned, preliminary tests were made as follows. The acuity of the observer was taken every 3 min. until no noticeable change was found. This length of time was then always allowed for that observer as an adaptation period prior to the loss of efficiency test conducted for the given intensity of illumination.[4]

We have results to show the effect of this and many other factors, but, as I have already stated, we have employed them only for our own guidance in standardizing the test. In short, our first concern and duty to the committee on which we are serving, as we have understood that duty, has been to bring the test to a certain degree of standardization and to describe the essential conditions of standardization rather than to take the time to

[4] To make still more certain that the eye has reached a constant state of adaptation or an unchanging state of sensitivity to the working light employed before the test for loss of efficiency is begun, a still longer preparatory period may be allowed than is indicated by the preliminary acuity tests. We would again emphasize also the importance during the loss of efficiency test of maintaining the eye in a fixed relation with the test object, *i. e.*, its distance from the test object must be kept constant, and care must be taken that there are no head-movements and as few involuntary eye-movements as possible during the test.

compile in the systematic way needed for publication the results we have obtained and used at various stages in the standardization of the test. In addition to the special precautions which have been mentioned at various points in the description of our investigations, the following are some of the more general precautions that are regularly taken in the conduct of the work. Care is exercised that there shall be at the beginning of the test no feeling of eye fatigue or discomfort, no physical fatigue, headaches, or other physical indisposition. Unusual or excessive work or strain, loss of sleep, etc., are not permitted the day before the tests are taken. In order further to guarantee that the physical and optical conditions of the observer are the same from test to test, the work is always begun at the same time of day, namely at 9 o'clock in the morning. In short, all the precautions known to us from our previous experience with eye work or discovered by us in the course of the present work are taken to exclude from the experiment every factor which is not included in the conditions to be tested.

In concluding I wish again to express my appreciation of the work that has been done by Mr. Cravath, and to venture the hope that he and others may further cooperate in the application of this and similar tests to the solution of the many problems relating to the hygienic employment of the eye.

REPORT OF COMMITTEE ON PRESIDENTIAL ADDRESS.*

Your committee begs to report as follows:

The address of the president is of such wide scope, so suggestive and so helpful, that the Society is to be congratulated on having received the same.

The committee has considerd in the first instance the suggestion that the Society should set up standards for the illumination of certain classes of interiors, *viz.*, those which are most numerous and typical. The committee, after giving careful consideration to this suggestion, has concluded that, while the president's proposition sets a worthy ideal for the Society's activity, to which the Society may reasonably hope to attain at some future time, at the present, in view of the multiplicity of illuminants and accessories and of the methods, many of them most excellent, for utilizing the same, and further, in view of the rapid development of the art at the present time, it would be premature to attempt such standardization now.

The second broad suggestion as made by the president is that the work of the Society should be further popularized and given a more widespread publicity through various channels. The suggestion, as it applies to school teachers and school children, we commend to the attention of the Council, with the suggestion that a propaganda of this kind might be carried out through the medium of lectures, along the lines of the primer,[1] before teachers' meetings in various localities and by additional and continued effort to circulate the primer among teachers and school children of the proper age. The suggestion as to the extension of sustaining membership among educational boards, philanthropic endowment and private philanthropists, we commend as worthy of the attention of the Society and its Council.

Respectfully submitted, CLAYTON H. SHARP,
JAS. R. CRAVATH,
GEO. S. BARROWS,
Committee on Presidential Address.

* A report presented at the eighth annual convention of the Illuminating Engineering Society, Cleveland, O., Sept. 21-25, 1914. The address appears in TRANS. I. E. S., vol. IX, p. 562.

[1] Light: Its Use and Misuse; Trans. I. E. S., vol. VII, p. 347.

REPORT OF COUNCIL FOR YEAR ENDING SEPTEMBER 30, 1914.

General.—At the end of the eighth year of the Society's existence, it is a genuine pleasure to report that the progress in the work and welfare during the past twelve months has been steady, consistent and altogether gratifying. General plans evolved in the preceding years were pursued along more extended lines of activity. In the membership there was a net gain of 75 individual and 14 sustaining members. The total membership at the end of the year was 1509. Altogether the sections had an unusually successful year. The TRANSACTIONS contained 35 per cent. more material than was published during the corresponding period last year. Nearly every paper published was abstracted or reprinted both in this country and abroad. Still another significant fact in the year's record, is the number of requests which have been addressed to the Society for information and co-operation on questions of lighting. Over 300 such requests were received and answered. The following tables and paragraphs give an outline of the year's record.

II.—MEMBERSHIP.

Table III shows the membership changes during the year.

Table IV gives a classification of members.

Table V shows in what states the membership losses and gains were made. It also serves to indicate the localities in which the Society is not adequately represented. The southern and far western states show a relatively small percentage of members.

TABLE III.—MEMBERSHIP CHANGES.

			Individual	Sustaining
Members October 1, 1913			1,397	21
Applications	148			
Reinstatements	14			
Total additions		162		
Resignations	84			
Deceased	3			
Total defections		87		
Net gain in membership during the year			75	14
Membership September 30, 1914			1,472	35

TABLE IV.—CLASSIFICATION OF MEMBERS.

Nature of business	Number members	Per cent. of total
Manufacturers of lighting accessories (engineers, department managers and salesmen)	373	25.34
Lighting companies (gas and electric) (engineers, department managers and salesmen)	561	38.11
Contractors and jobbers (engineers, department managers and salesmen)	161	10.94
Research and testing laboratories	42	2.48
Consulting engineers	110	7.47
Pedagogues	69	4.68
Oculists and ophthalmologists	20	1.36
Municipal and public service authorities	43	2.92
Managers, superintendents and owners of industrial buildings, etc.	24	1.63
Trade and technical journals	22	1.49
Architects	13	0.88
Unclassified	34	2.31
Total	1.472	100.00

TABLE V.—GEOGRAPHICAL CLASSIFICATION OF MEMBERS, SHOWING THE NET CHANGES DURING THE YEAR ENDING SEPTEMBER 30, 1914.

United States.

State	Members	Net changes	Sustaining members	Net changes
Alabama	..	—2	..	..
Arkansas	..	..	1	..
California	29	10	..	..
Colorado	6	—1	..	..
Connecticut	16	3	..	..
District of Columbia	18	1	..	..
Florida	3	..	..	..
Georgia	5	—2	1	..
Illinois	143	14	4	2
Indiana	20	..	..	..
Iowa	12	2	..	..
Kansas	4	2	..	..
Kentucky	4	2	..	..
Louisiana	4	..	..	..
Maine	5	1	..	..
Maryland	22	1	1	..
Massachusetts	81	5	3	1
Michigan	19	2	..	..
Minnesota	10	1	..	..
Missouri	18	1	..	..

TABLE V.—(*Continued.*)

States	Members	Net changes	Sustaining members	Net changes
Nebraska	4	..	..	..
New Hampshire	3	—1	..	..
New Jersey	90	—1	3	..
New York	357	10	10	5
North Carolina	2	..	..	..
North Dakota	1	1	..	..
Ohio	98	6	4	2
Oklahoma	1	—1	..	..
Oregon	5	—2	..	..
Pennsylvania	355	7	5	1
Rhode Island	7	2	..	..
South Carolina	2	..	..	..
South Dakota	1	—1	..	..
Tennessee	2	1	..	..
Texas	8	4	..	..
Utah	3	—1	..	..
Vermont	2	1	..	..
Virginia	6	1	..	..
Washington	5	..	..	..
West Virginia	4	1	1	1
Wisconsin	27	1	..	..
Wyoming	1	1	..	..
	1,403	69	33	12

Foreign and Territorial.

Canada	23	1	2	2
China	1	1	..	..
England	20	3	..	..
France	3	..	..	..
Germany	7	1	..	..
Hawaii	..	—1	..	..
Ireland	1	1	..	..
Japan	2	1	..	..
Mexico	..	—1	..	..
Panama	..	—1	..	..
Philippines	2	..	..	..
South America	8	..	..	..
Spain	2	1	..	..
	69	9	2	2
		—3		
		6		

III.—SECTIONS.

Table VI gives an interesting summary of section activities.

TABLE VI.—SECTION ACTIVITIES.

	Number meetings held	Average attendance	Number papers contributed to TRANSACTIONS	Net gain in membership	Total number members September 30, 1914
Chicago	9	64	4	16	243
New England	2	137	..	7	93
New York	8	146	6	23	452
Philadelphia	9	134	5	11	353
Pittsburgh	9	54	6	—1	159
General	..	..	..	19	172
				+75	1,472

IV.—COMMITTEES.

The following paragraphs summarize the work of the twenty-seven standing committees during the year.

1914 Convention Committee.—The eighth annual convention which was held in Cleveland, Ohio, September 21-25, 1914, was an unqualified success. All the numerous arrangement details were handled with smoothness and despatch. The program of papers, 29 in all, was so large as to necessitate parallel commercial and scientific sessions on one day. The numerous written and oral discussions contributed indicated that the papers, as a whole, were especially attractive. The registration totaled 300. The average attendance at the commercial session was 100, the scientific session 40, the mixed sessions 110. The entertainment was especially pleasing, and provided a nice balance between work and play.

Committee on Glare from Reflecting Surfaces.—The campaign started two years ago for elimination of those glazed and polished surfaces whose reflections produce ocular discomfort and injury was continued. Sufficient evidence in the way of inquiries, particularly in regard to non-glossy printing papers, has come to hand to show that the committee's efforts have been effective. While the effects of such a campaign are not susceptible to measurement, it goes without saying that the strong influence exerted against the glare evil has produced beneficial results. Much missionary work, however, still remains to be done. For in-

stance, the manufacture of a cheap paper satisfactory for the commercial reproduction of half-tones, needs encouragement, and buyers of printing need to be further impressed with desirability of using non-glossy paper.

Committee on Popular Lectures.—The work of collecting material for a series of popular lectures on the lighting of several interiors started over a year ago and has been pushed toward completion. One lecture deals with the general principles of illumination; the other five are devoted to residence, office, industrial, store and school lighting respectively. Two of the lectures are practically completed. In all the lectures, which are to be made available for presentation before the public and other meetings, the principles and information to be imparted will be reduced to a simple and attractive form. It is hardly necessary to say that the dissemination of knowledge in this way will do much to, first, eliminate those evils of poor lighting which menace public health and cause enormous economic losses; second, create demand for better lighting.

The Committee on Reciprocal Relations with Other Societies, has continued to promote closer relations between the I. E. S. and those associations which are concerned with the subject of illumination. During the past year it has been in communication with some 36 different societies in an effort to arouse greater interest in the better illumination propaganda. Eleven of these were associations of school teachers; 6 were medical societies; 10 engineering and professional; and 9 commercial and manufacturing association. Some 14 joint meetings of sections of the I. E. S. with these societies were held largely as a result of the committee activities.

Lighting Legislation Committee.—Under the direction of this committee the compilation of a digest of the laws relating to lighting in certain states was undertaken. Thus far the laws of the state of Pennsylvania, Connecticut and New York have been collated.

Committee on Education.—A canvass of the larger colleges in this country was made to ascertain what is being done in the way of instruction and laboratory work in illuminating engineering. The committee has prepared (1) a tentative outline of a curri-

culum covering a four year's course of study which might lead to the degree of illuminating engineer; an outline of an adjunct course covering one year of under graduate work, and one-year post graduate work. (2) An interesting analysis of text books, printed in English, dealing with one or more phases of illuminating engineering.

The Research Committee held several meetings, each one of which was devoted to a discussion of some problem on which further information and research is desired. Summaries of these discussions with extensive bibliographies on the subjects have been published in the form of reports in the TRANSACTIONS.

Progress Committee.—In its annual report the committee presented a comprehensive review of the progress in the field of illumination as recorded in foreign and domestic journals during the year. There was also included much valuable information that had not been previously published. The report has been published shortly in the No. 6 issue of the 1914 TRANSACTIONS.

Committee on Nomenclature and Standards.—This committee, as in the past, has endeavored to promote American, and to some extent, international, agreement in questions of units and terminology.

Papers Committee.—This committee has passed on all papers and technical reports submitted for publication in the TRANSACTIONS. It arranged the papers program for the 1914 Convention and passed on the technical reports submitted to the convention. At the request of the Committee on Reciprocal Relations, speakers were provided for meetings of a number of associations and societies, interested in illumination. It has co-operated with some of the section papers committees in the preparation of their programs.

The Committee on Editing and Publication has exercised supervision over all the editorial and publication work in connection with the TRANSACTIONS.

Membership Committee.—The members of the Society were all solicited for the names of prospective members. The names of other prospective members were obtained from: (1) The membership rolls of some 9 or 10 societies which are more or less interested in the subject of illumination; (2) Thirty jour-

nals, for the names of men who have written articles on various phases of lighting during the past few years. From all of the above mentioned sources 1,500 names were obtained. To these prospective members it is proposed to issue shortly an invitation to join the society, enclosing a pamphlet.

International Commission on Illumination.—The Society has participated in the organization of the United States Committee of the International Commission on Illumination, delegating members to serve upon the United States Committee and contributing toward the support of the international work. While of course this movement has come to a stop because of the war, yet the foundation for furthering the international effort has been laid.

Committee on Advertising.—The amount of advertising in the TRANSACTIONS during the past year was slightly below that of the previous 12 months. In the beginning of the year, some efforts were made to increase the amount of advertising, which resulted in several new contracts.

Sustaining Membership Committee.—During the year the committee added 14 new sustaining members to the roll of the Society.

Committee on Section Development.—An effort was made by correspondence to promote closer co-operation among the sections in regard to details of management. [A number of valuable ideas were exchanged by sections.]

The Board of Examiners, and the *Committee on Tellers* of the annual election are two committees, the importance of whose work is often overlooked in the mass of committee work accomplished each year. The work of both these committees involved considerable detail.

V.—LOCAL SECRETARIES.

In a number of instances our local representatives have rendered valuable service in increasing the local membership; and in directing attention to the work of the Society. One representative procured for a meeting of a local chapter of a sister organization several papers on illumination.

VI.—TRANSACTIONS.

The number of pages published in the TRANSACTIONS totaled 1,002, an increase of 35 per cent. over the TRANSACTIONS issued during the previous 12 months.

VII.—RELATION WITH OTHER SOCIETIES.

The relations between the I. E. S. and sister societies during the past year have been most cordial. Through the efforts of the Committee on Reciprocal Relations, closer relations have been formed with many sister societies. Several organizations signified their desire to co-operate with the I. E. S. on questions relating to illumination.

FINANCIAL REPORT.

November 12, 1914.

To the Council of the Illuminating Engineering Society:

We beg to hand you attached a report just received from Messrs. William J. Struss & Company, certified public accountants, dated November 5, 1914, showing the income and expenses for the fiscal year just ended and also the financial status of the Society as of September 30, 1914. You will note from the report that the Society closed its fiscal year with a deficit of $622.92. This deficit was occasioned:

(1)—By the falling off of revenue and,

(2)—By an increase of expenses over the anticipated amount based upon the budget prepared at the beginning of the last fiscal year. The largest single item of expense was the printing of the TRANSACTIONS. You will notice that the amount estimated in the budget for this work was $3,000. Actual bills passed for payment amount to $3,873.68, making an increase of expense in this one item of $873.68.

By making a careful study of the several committee expenses, you will notice that in some cases the expenses were higher, whereas in others they were lower.

A. HERTZ,
W. J. SERRILL,
C. A. LITTLEFIELD, *Chairman.*

MR. C. A. LITTLEFIELD, November 5, 1914.
Chairman, Finance Committee,
Illuminating Engineering Society,
New York, N. Y.

DEAR SIR:—

In accordance with your instructions we have examined the books and accounts of the Illuminating Engineering Society for the twelve (12) months ended September 30, 1914.

The results of this examination are set forth in the two exhibits, attached hereto, as follows:

EXHIBIT "A"—Balance Sheet, September 30, 1914.

EXHIBIT "B"—Earnings and Expenses, for the twelve months ended September 30, 1914.

The cash over-draft as shown on the Balance Sheet ($402.99) is occasioned by the drawing of checks for all known outstanding debts of

the Society. Sufficient of these checks were held to protect an "actual over-draft."

We hereby certify that the accompanying Balance Sheet is a true exhibit of its financial condition as of September 30, 1914, and that the attached statement of Earnings and Expenses is correct.

Respectfully submitted,

(Signed) WM. J. STRUSS & CO.,
Certified Public Accountants.

ILLUMINATING ENGINEERING SOCIETY.

BALANCE SHEET, SEPTEMBER 30, 1914.

EXHIBIT "A."

Assets.

Cash on hand		$ 100.00
Accounts receivable:		
1914—Dues, sustaining members	$ 300.00	
1914—Advertising	192.84	
1914—Initiation fees	25.00	
1914—Dues	85.00	
1914—TRANSACTIONS	40.00	
1914—Reprints	38.73	
1914—Primer	35.40	
1914—Miscellaneous	12.00	
1913—Miscellaneous	5.25	
		734.22
Investments:		
Northern Pacific & Great Northern Railway Bonds—$2,000 (book value)		1,920.00
Furniture and fixtures		684.81
Badges on hand		27.50
Primers on hand		75.80
Prepaid charges		30.00
		$3,572.33

Liabilities.

Cash—Bank over draft	$ 402.99	
Outstanding debts, estimated	869.58	
Advance dues	878.75	
Advance sustaining dues	20.00	
		$2,171.32
Surplus account—Balance Oct. 1, 1913	$1,865.40	
Miscellaneous adjustments	158.53	
	$2,023.93	
Net loss for the twelve months ended September 30, 1914, as per Exhibit "B"	622.92	
		1,401.01
		$3,572.33

ILLUMINATING ENGINEERING SOCIETY.

Statement of Earnings and Expenses for the Twelve Months Ended September 30, 1914.

Exhibit "B."

Earnings.

Members' dues		$7,069.75	
Sustaining dues		2,790.00	
Initiation fees		340.00	
Advertising		1,407.12	
Transactions sales		420.93	
Reprint sales		16.55	
Primer sales		70.45	
Badge sales		9.00	
Certificates sales		5.05	
Miscellaneous		11.00	
Interest earned		78.24	
Total			$12,218.09

Expenses.

Transactions		$3,873.68	
General Office—Salaries	$3,137.49		
Rent	855.96		
Stationery and printing	431.67		
Postage	349.35		
Telephone and telegraph	127.38		
Miscellaneous	237.32		
		5,139.17	
New York Section		357.71	
Philadelphia Section		211.68	
Chicago Section		289.95	
Pittsburgh Section		296.72	
New England Section		66.92	
Committee on Sustaining Membership		194.60	
Committee on Education		46.75	
Committee on Reciprocal Relations		11.11	
Committee on Glare		39.53	
Committee on Membership		239.45	
Committee on Research		10.92	
Committee on Lighting Legislation		50.00	
Committee on Popular Lectures		11.72	
Committee on Lighting Exhibit		107.49	
Joint meetings with other societies		32.25	
Election expenses		83.13	
Miscellaneous expense		245.72	
Exchange and discount		24.82	
Depreciation of furniture and fixtures		120.84	
Convention 1913		1,386.85	
Total			12,841.01
Excess of Expenses over Earnings			$622.92

TRANSACTIONS

OF THE

Illuminating Engineering Society

NO. 9, 1914

PART II

Miscellaneous Notes

Council Notes.

A meeting of the Council was held December 10 in the general office, 29 West 39th Street, New York. Those present were: A. S. McAllister, president; E. M. Alger, C. O. Bond, H. Calvert, C. A. B. Halvorson, Jr., George A. Hoadley, L. B. Marks, Preston S. Millar, A. S. Miller, W. Cullen Morris, G. H. Stickney; and H. H. Magdsick, representing Ward Harrison, and M. Luckiesh, chairman of the School Lighting Committee, upon invitation.

A budget for the present fiscal year was received from the Finance Committee.

Upon recommendation of the Finance Committee payment of vouchers Nos. 1913 to 1942 inclusive aggregating $553.16 was authorized.

Written reports on section activities were received from Messrs. G. H. Stickney, vice-president of the New York Section; George A. Hoadley, vice-president of the Philadelphia Section; and H. H. Magdsick representing Ward Harrison, vice-president of the Pittsburgh Section.

The following resolution, which was submitted by the Committee on Nomenclature and Standards, was approved:

Resolved, That it is the opinion of this Committee

(*a*) That the output of all illuminants should be expressed in lumens,

(*b*) That illuminants should be rated upon a lumen basis instead of a candle-power basis,

(*c*) That the specific output of electric lamps should be stated in lumens per watt and the specific output of illuminants dependent upon combustion should be stated in lumens per British thermal unit per hour.

A written report from the Exhibition Booth Committee (Electric) was read by Mr. H. H. Magdsick, representing Mr. Ward Harrison, chairman.

Resolved, that a vote of thanks be extended to Mr. Ward Harrison, chairman of the Exhibition Booth Committee (Electric) for the excellent work he has done in arranging the exhibition booths and preparing them for the road.

A report of the year's work of the Committee on Education for the year ending September 30, 1914, was presented by Mr. Preston S. Millar, chairman. The report contains (1) a summary showing the extent of instruction in laboratory work in illuminating engineering at thirty-nine schools and colleges, (2) a complete curriculum for a four-year undergraduate course leading to an illuminating engineering degree, (3) a one-year undergraduate adjunct course, (4) a one-year post-graduate course, and (5) a classified list of books, in English, pertaining to illuminating engineering.

It was resolved that a vote of thanks be extended to the Committee for its excellent work and extensive report submitted.

A written report of progress was received from the Committee on Papers.

The following committee appointments were confirmed:

Research Committee: E. B. Rosa, chairman; P. W. Cobb, E. C. Crittenden, C. E. Ferree, E. P. Hyde, H. E. Ives, E. F. Kingsbury, Preston S. Millar, G. W. Middlekauff, P. G. Nutting, F. K. Richtmyer, C. H. Sharp, and W. E. Wickenden.

Committee on Time and Place: G. H. Stickney, chairman; C. A. B. Halvorson, Jr., Ward Harrison, George A. Hoadley, and F. A. Vaughn.

A list of general instructions for committees was adopted. It was ordered that these instructions, together with a list of suggestions for committee work, be submitted to each committee. It was understood that the plan of work for each committee for the coming year would be submitted at the next Council meeting.

A written report of the work of the International Commission on Illumination for the year 1914 was presented by Mr. Preston S. Millar, a representative of the Illuminating Engineering Society on the United States National Committee of the International Commission on Illumination.

A written report of progress was received from the Committee on Reciprocal Relations.

A written report was received from the Committee on School Lighting.

Section Notes.

CHICAGO SECTION

The tentative program of papers for the Chicago Section for the rest of the season 1914-1915 is as follows:

December—The Eye: Physiology of Sight. Psychology of Seeing.

January—Incandescent Light Sources (Gas and Electric).

February—Other Light Sources (Gas and Electric).

March—Decoration: Color Schemes; Fixture Forms; Use of Colored Sources.

April—Lighting of Small Interiors: Homes; Small Offices; Show Windows.

May—Lighting of Large Interiors: Churches; Halls; Large Offices.

June—Lighting of Open Air Spaces: Streets; Building Exteriors; Signs.

NEW YORK SECTION

A meeting of the New York Section was held Thursday evening, December 10, 1914, in the Engineering Societies Building. Mr. George W. Cassidy presented a paper, "The Art and Science in Home Lighting." The paper was supplemented by an interesting exhibition of gas and electric lamps and fixtures for home lighting, which was arranged by a number of manufacturers. The usual informal dinner was held previous to the meeting at Keen's Chop House on 36th Street.

The tentative program for the rest of the year is as follows:

January—Joint meeting with the Professional Photographers Club. Paper "The Type C and Cooper Hewitt Lamps for Use for Photography" by a representative of the Professional Photographers Club. It is also planned to have two other papers: one by Mr. M Luckiesh of the Nela Research Laboratory, representing the Illuminating Engineering Society, on "The Use of New Lamps for Photography," and the other by Williamson Brothers on the subject "Submarine Photography."

February—"The Type C Lamp for Street Lighting" by Mr. W. H. Rolinson; "The Magnetite Lamp for Street Lighting" by Mr. C. A. B. Halvorson, Jr.

March—This meeting is to be arranged by the Fine Arts Committee of the Section. There will be a symposium on light by various artists, decorators and architects; each speaker to take about ten minutes to explain the needs of his profession in lighting.

April—Tentative plans for a meeting of the New York sections of the Illuminating Engineering Society, the National Commercial Gas Association and The National Electric Light Association to discuss the commercial side of the good lighting propaganda.

May—A joint meeting of New York sections of the Illuminating Engineering Society and the American Institute of Electrical Engineers.

June—Dr. Hollis Godfrey of Philadelphia, Pa., has been invited to present a paper on "Good Lighting as an Aid to Welfare Work" to include a description of the work which he has done in the Metropolitan Life Insurance Building in New York.

PHILADELPHIA SECTION

A meeting of the Philadelphia Section was held December 18, 1914, in the Engineers Club. Two papers were presented at this meeting: "Recent Developments in Gas Lighting" by Mr. T. J. Litle, Jr., and "New Methods and Devices in the Control and Distribution of Electric Lighting Installations" by Mr. Washington Devereux. After the meeting gas lamps and electrical control devices were exhibited.

The following program for the rest of the year has been announced:

January 15—"Amusement Park Lighting—Lighting of Willow Grove Park" by Mr. Harry Markle; "Piping Houses for Gas Lighting" by Mr. H. H. Sterrett.

February 8—Joint meeting with American Institute of Electrical Engineers. "A Year's Progress in Illumination" by Prof. Geo. A. Hoadley; "Recent Developments and Applications of Electric Incandescent Lamps" by Mr. Geo. H. Stickney. Electric lamps will be exhibited.

February 19—"Scientific Management" by Mr. Frederick W. Taylor. A demonstration of the pathescope, a new moving picture device, will be given.

March 19—"A Method of Securing Uniformity of Reading of the Flicker Photometer with Different Observers" by Dr. Herbert E. Ives and Mr. E. F. Kingsbury. Photometric apparatus will be exhibited.

April 16—"The Problem of Lighting Design." (Methods used for designing: (*a*) direct lighting; (*b*) indirect lighting; difficulties and faults in the use of such methods; accuracy to be expected in the results accomplished; what constitutes good design?) By Prof. Arthur J. Rowland. Exhibition of new types of lighting fixtures.

May 21—"Store Lighting" by Mr. W. R. Moulton. This meeting will be held in Baltimore, Md. The place will be announced later.

PITTSBURGH SECTION

The following tentative program for the year has been announced.

December—A joint meeting with the Academy on Science and Art. A lecture by Dr. Bancroft of Cornell University on "Cold Light."

January—A joint meeting with several engineering societies, and a popular lecture, accompanied by demonstrations, on school lighting and optical hygiene. This meeting will be held in Cleveland, O The date will be announced later.

February—To be announced later.

March—Joint meeting with the American Institute of Electrical Engineers. Paper: "Headlights and Projections" or "Modern Lamp Manufacture."

New Members

The following applicants were elected members of the Society at a meeting of the Council held December 10, 1914:

JONES, LOYD A.
Physicist, Research Laboratory, Eastman Kodak Co., Rochester, N. Y.

LEIBMAN, GEORGE J.
Chief Clerk of Sales Department, Edison Electric Illuminating Co. of Brooklyn, 360 Pearl St., Brooklyn, N. Y.

MACKIE, J. W.
Supt. of Meters and Industrial Eng., Municipal Gas Co., Electric Department, 71 Trinity Place, Albany, N. Y.

RAETZ, EDWIN M.
Electrical Contractor and Dealer, 222 S. Broadway, Rochester, Minn.

SPURR, J. R.
Manager, Monolux Sales Co., 105 W. 40th St., New York, N. Y.

Sustaining Membership.

The Drexel Institute of Philadelphia, Pa., was elected a sustaining member of the Society at a meeting of the Council held December 10, 1914.

Committee on Lighting Legislation.

The Committee on Lighting Legislation of the Illuminating Engineering Society is desirous of co-operating with legislators, organizations, committees, or others interested in the enactment or amendment of laws or regulations pertaining to lighting. The committee has made a study of lighting legislation and has collated the lighting statutes of several states. The scope of its work covers not only artificial light but daylight and includes both interior and exterior lighting. Address all communications to the committee at the general offices of the Society, 29 West 39th Street, New York City.

Index Volume IX.

The index for Volume IX (1914), TRANSACTIONS of the Illuminating Engineering Society, will be mailed with the No. 1 issue of Volume X which will be published February 10, 1915.

New Books.

AMERICAN HANDBOOK FOR ELECTRICAL ENGINEERS—compiled by Harold Pender and a staff of specialists; 969 pp., $5.00; John Wiley & Sons Co., Inc., 432 Fourth Avenue, New York. Contains treatment of the following topics: laws of vision; photometric quantities and photometry; laws of illumination; incandescent lamps; arc lamps; gas lighting; lighting plants; lighting substations; interior illumination; street illumination; train lighting by electricity.

PRACTICAL LESSONS IN ELECTRICITY—by Millikan, Crocker & Mills; 329 pp., $1.50; American Technical Society, Chicago. Arranged in four parts dealing with: elements of electricity and magnetism; direct-current dynamos—principles; elements of alternating currents; storage batteries.

ELECTRICAL MEASUREMENTS—by Bushnell & Turnbull; 171 pp., $1.00; American Technical Society, Chicago. Contents: units of measurement; primary standards; electrical measuring instruments; methods of measurement; watt-hour meters; watt-hour meter records; measurement of maximum demand.

Erratum.

On the eighth line from the top on page 705 (No. 8) of Volume IX of the TRANSACTIONS, the figure 45 watts per candle should read 0.5 watt per candle.